Innovation of product modularity development through the integration of a formal Industrial Design framework

This item was submitted to Loughborough University's Institutional Repository by the/an author.

Additional Information:

- A Doctoral Thesis. Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University.

Metadata Record: https://dspace.lboro.ac.uk/2134/18670

Publisher: © Muhammad Firdaus Abong Abdullah

Rights: This work is made available according to the conditions of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0) licence. Full details of this licence are available at: https://creativecommons.org/licenses/by-nc-nd/4.0/

Please cite the published version.
INNOVATION OF PRODUCT MODULARITY DEVELOPMENT THROUGH THE INTEGRATION OF A FORMAL INDUSTRIAL DESIGN FRAMEWORK

By

MUHAMMAD FIRDAUS ABONG ABDULLAH

A Doctoral Thesis
Submitted in partial fulfillment of the requirements for the award of
Doctor of Philosophy

Loughborough Design School
Loughborough University
The United Kingdom of Great Britain
2015

© Muhammad Firdaus Abong Abdullah 2015
ACKNOWLEDGEMENTS

The Author wishes to thank:

Dr. Russell Marshall for his help, guidance and advice, and patient supervision of all aspects of
the research performed over the research period. Dr. Ian Campbell and my research colleagues
for their support in the topic.

The industrial contact: Mr. Olivier Carlens who was the Head of Product Development at the
time of the research, and all employees at the design department of FN Herstal, S. A. (The
Herstal Group of Companies), Liège, Belgium.

The sponsors: The Ministry of Education of Malaysia and Universiti Malaysia Sarawak for their
financial sponsorship and support over the research period.

My father and my late mother for their faith in my decision.

My wife Zarina and my sons, Hafiz and Haris for their love and support.
ABSTRACT

INNOVATION OF PRODUCT MODULARITY DEVELOPMENT THROUGH THE INTEGRATION OF A FORMAL INDUSTRIAL DESIGN FRAMEWORK

Growing numbers of global manufacturers are not only adopting the modularity concept, but integrating design methodologies that explicitly focused on achieving a range of competitive advantages through the enhancement of product appearance and utilities designs. The rising interest in industrial design is also an interesting symptom of changes in the approach to new product development, hence, integrating industrial design in modular product design posed a new challenge. In meeting these challenges, a formal Industrial Design framework known as InDFM (Industrial Design Framework for Modular Product Design/Development) was developed to support the innovation of design in modular product development. Within the InDFM, a methodology is developed for modular product design realisation.

This research embarked with identifying the appropriate range of product as the focus of the investigation, followed by qualitative surveys on the design and development processes relevant to the selected product. The surveys were conducted in modular product companies within a range of industries related to the product, in the U.K., Belgium and Malaysia. Literature reviews were also conducted on related domains across a range of application to understand the fundamentals of modularity and industrial design processes that are relevant to the domains. Data findings from these exercises were used to identify InDFM construction components, which were also vital to develop a technical standard for implementation of the InDFM. To evaluate its practicability, the InDFM was retrospectively applied in an existing modular product design process of a selected company. The evaluation focused on process compatibility of industrial design and modular design processes. Validation of the process compatibility emphasised the quality of integration at all stages of the design and development process.

In conclusion, industrial design applications in a highly technical process of modular product design provide a design-driven innovation to complement the engineering driven innovation in the process. The combinations were proven to enhance the visual, interactive, and the feasibility contents of a modular product apart from providing a broader perspective to the objective of product modularity. InDFM also provides design practitioners with systematic design methodology to integrate both processes, thus performed as a tool for innovation that facilitate the revision of object identity, break away from the existing design rules and generating new rules. Additionally, as InDFM is a flexible methodology, innovation of modular product design through industrial design is accessible to any product company, small scale or big organisation that would want to acquire an advanced interactive version of the InDFM in the future.
# List of Content

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERTIFICATE OF ORIGINNATY</td>
<td>i</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF CONTENT</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF FIGURE</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF TABLE</td>
<td>xiii</td>
</tr>
<tr>
<td>GLOSSARY OF KEY TERMS</td>
<td>xvi</td>
</tr>
</tbody>
</table>

## Chapter 1

1 Introduction

1.1 Background
1.2 Motivations
1.3 The Need
1.4 Aims and Objectives of Research
1.5 Scope of Research
1.6 Focus of Research
1.7 Thesis Outline

## Chapter 2

2 Research Methodology

2.1 Methodology Characteristics
2.1.1 Action Research
2.1.2 Strengthening the Action Research
2.2 Individual Research Context
2.2.1 Research Articulation
2.2.2 Investigation Survey
2.2.3 Framework Development
2.2.4 Framework Finalisation
2.3 Literature Review Approach
2.3.1 Relative Research Article Search
2.4 Investigation Methodology
2.4.1 Investigation Set-up Structure
2.4.2 Implementation

## Chapter 3

3 Product Design and Development Process Literature

3.1 Product Innovation
3.2 Product Development
3.2.1 The Product Development Process
3.2.2 Ideal ISO 9001 Design and Development Process
3.2.3 Product Development Category
3.2.4 Product Development Organisations
3.3 Product Design
3.3.1 Characteristics of Successful Product Design 40
3.3.2 Creative and Innovative Product 41
3.3.3 Product Styling 42
3.3.4 Product Industrial Design 43
3.3.4.1 Industrial Design Process 44
3.3.4.2 Innovation through Industrial Design 46
3.3.5 Industrial Design in Product Development Process 48
3.3.6 Industrial Design Measures 49
3.3.6.1 Emphasis 50
3.3.6.2 Capability 50
3.3.6.3 Outcome 51
3.3.6.4 Management 51
3.4 Defining Product Architecture 52
3.4.1 Implication of the Architecture 54
3.4.2 Establishing the Product Architecture 55
3.4.3 Modular Product Architecture 56
3.5 Mass Customisation 57
3.5.1 Techniques and Classifications of Mass Customisation 58
3.5.2 The Best Method of Mass Customisation 59
3.6 Modular Product Design and Development 60
3.6.1 Definition of Modularity 61
3.6.2 Characteristics and Typologies of Modularity 62
3.6.3 The Need for Modularity 65
3.6.4 Modularity and Cost 66
3.6.5 Modular Product Design Process 67
3.6.6 Principles of Modular Design 69
3.6.7 Modular Product Overview 70
3.7 The Strategic Objectives of Industrial Design Innovation in Modular Product Design 73
3.8 Industrial Design Innovation in Modular Rifle System Design 76

Chapter 4
4 Industrial Design Analysis in Modular Product Design 81
4.1 Determining the New Industrial Design 81
4.2 Investigation Process Perspective 82
4.2.1 Investigation Quality Perspective 85
4.2.2 Quality Perspective of Measurement Group 86
4.2.3 Quality Perspective of the Representation Group 87
4.3 Outcome of Investigation 90
4.3.1 Category 1 – The Perception of Industries towards Industrial Design in the Product Development Process 90
4.3.1.1 Industrial Design in Product Strategic Planning 91
4.3.1.2 Industrial Design Involvement in Product Development Process 94
4.3.1.3 Anticipated Industrial Design Application 97
4.3.1.4 Design Services provided by Industrial Design Practitioners and Organisations 100
4.3.1.5 Investigation Summary 103
4.3.2 Category 2 – The Importance of Industrial Design in Modular Product Development 104
4.3.2.1 Industrial Design Needs in Modular Product Design 106
7.5 Future Work

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bibliography</td>
<td>199</td>
</tr>
<tr>
<td>Index 1 – Questionnaire I</td>
<td>213</td>
</tr>
<tr>
<td>Index 1 – Questionnaire II</td>
<td>218</td>
</tr>
<tr>
<td>Index 1 – Questionnaire III</td>
<td>226</td>
</tr>
<tr>
<td>Index 1 – Questionnaire IV</td>
<td>231</td>
</tr>
<tr>
<td>Index 1 – Questionnaire V</td>
<td>238</td>
</tr>
<tr>
<td>Index 2 – Interview Survey</td>
<td>244</td>
</tr>
<tr>
<td>Index 3 – Checkpoint, QC &amp; QA Priority Level, Evaluation Form</td>
<td>252</td>
</tr>
<tr>
<td>Index 4 – Product Development Process Reference</td>
<td>279</td>
</tr>
<tr>
<td>Index 5 – Survey Presentation</td>
<td>280</td>
</tr>
<tr>
<td>Index 6 – Article 1</td>
<td>281</td>
</tr>
<tr>
<td>Index 6 – Article II</td>
<td>293</td>
</tr>
</tbody>
</table>
# List of Figure

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1</td>
<td>Philips electric shaver series (Philips Electronics, 2010)</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>The generic processes applied in design and development of new product (Adopted from: FN Herstal, 2007)</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>The research scope</td>
</tr>
<tr>
<td>Figure 1.4</td>
<td>The <em>Sturmgewehr 44</em> (StG 44) firearm generally considered the first assault rifle that served to popularise the concept and form the basis for today's modern assault rifles.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>Overview of the actual (Individual) research phases based on triangulation methodology used in the development of InDFM</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>ScienceDirect subject browser (ScienceDirect, 2008)</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>MetaLib search page (Loughborough University UK, 2009)</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Investigation methodology design set-up structure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 3</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 3.1</td>
<td>General sequence of activities in generic product development process (Adopted from Kamrani, 2000; Ulrich and Eppinger, 2000)</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>A visible operational structure of ‘Total Design’ which is separated into six iterative stages of the design process. The structure enables uninterrupted flow of information between stages while enabling the formation of multi-discipline project teams (Source: Pugh, 1991)</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>The ideal ISO 9001 Design and Development Process (Adopted from: American Society of Quality Control, 1994)</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Dyson Ball range of Dyson vacuum cleaner – The innovative roller ball concept makes the product more maneuverable and steers smoothly with a turn of the users’ wrist. The centrifugal suction technology innovation also gives the product added advantages as it does not require any dust bags therefore it has no loss of suction. (Dyson Limited, 2008)</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>American car such as the Cadillac 1959 features streamline bodies with tailfins and heavy chrome front.</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>Generic industrial design process (Adopted from: Ulrich &amp; Eppinger, 2000)</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Malaysian made CSL mobile phone introduced the latest <em>Android</em> application <em>Spice</em> series model with essential Islamic features that appeal to most Muslim users in Malaysia such as the ‘azan’ and the direction of the Ka’bah (Image source: Spice CSL International, 2011)</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Disney’s cartoon characters wearing traditional Chinese attires demonstrated the integration of local culture into a Disney’s product, albeit randomly, has successfully captured the hearts of Chinese customers to visit Hong Kong Disneyland (Image: © The New York Times, 2009)</td>
</tr>
</tbody>
</table>
Industrial design (8) in generic product development process (Adopted from Ulrich and Eppinger, 2000)

An Formula 1 racing car design embodies an integral architecture for optimisation of performance on different circuit (F1grandprix.net, 2014)

Embodiment of modular architecture for the desktop computer enables configuration of unlimited number of product variation through configuration of physical components and software (Hp Computers, 2010).

Scania’s modular truck cab. The modularised cab provides greater improvement in product re-configurability which increases variety and the speed of introduction of new product into the market (Ericsson and Erixon, 1999)

Levels and approaches of mass customisation (Adopted from: Broekhuizen, 2002)

Modular car concept which allows mix and match of roof component to create the desired final model (Diamler Chrysler AG, 2007)

Module Characteristics and typologies (Adopted from Arnheiter & Harnen, 2005)

Component-swapping modularity (Adopted from: Kamrani & Salhieh, 2000)

Component-sharing modularity (Adopted from Kamrani & Salhieh, 2000)

Fabricate-to-fit modularity (Adopted from Kamrani & Salhieh, 2000)

Bus modularity (Adopted from Kamrani & Salhieh, 2000)

Modular product design process (Adopted from: Kamrani & Salhieh, 2000)

Some examples of Swatch wristwatches sharing similar platform. Almost all the watches use similar platform, which is simple and cheap to manufacture, and capable of supporting extensive external variations (Swatch AG, 2007)

Black & Decker cordless drill series. The uses of common platform enable the company to produce many variations of cordless drill customised to different users’ requirement (blackanddecker.com, 2013).

Volkswagen’s Modular Transverse Matrix will underlie the new Audi A3 and Volkswagen Golf (Credit: Volkswagen)

Models of Airbus aircrafts share the same fuselage cross-section and significant component commonality (Airbus Industries, 2010)

A different design concept of modern bicycle formed the basis of extensive product lines

The variable styling of executive office chair

Styling variations are needed to differentiate individual product models of digital camera within the total product family (Nikon UK Ltd., 2010).

Flat screen television technology has developed rapidly from Plasma technology to LCD technology, and the latest being LED 3D technology with motion and voice command (Samsung Electronics Ltd., 2013).

The new texture and shades design to function as integrated jungle
camouflage without covering the rifle with extra camouflage materials (Copyrights © eHobbyAsia, 2013)

Figure 3.30 Styling variations can effectively distinguish individual product models within the modular product families (Special Forces) while providing distinctive (General operation and desert operation) and unifying design theme to the total product family (Copyrights © FN Herstal, 2010)

Figure 3.31 Integration of operation boosting devices significantly enhanced the operation capability and aiming accuracy of the concept rifle (Copyrights © Anemos Major, 2013)

Chapter 4
Figure 4.1 Investigation methodology design sets up structure
Figure 4.2 Investigation quality assurance measures
Figure 4.3 Application rating of functions in strategic product planning. Functions: 1-R&D; 2-Organisation; 3-Industrial design; 4-Manufacturing; 5-Marketing; 6-Information technology; 7-Engineering; 8-Sales
Figure 4.5 Potential future roles of the Industrial Designer; the role of industrial design has diversified from the traditional ‘master of aesthetics’ to broader technical fields, which include product engineering and research.
Figure 4.6 The graph shows the analysis output of the perceived current and future demand of industrial Design in product development. Roles: 1 – Product researcher; 2 – Product stylist; 3 – Technician; 4 – Creative leader; 5 – Product engineer
Figure 4.7 This graph shows the percentage of the identified services provided by industrial design practitioners and companies. Services: 1 – Product modeler; 2 – Product stylist; 3 – CAD/CAM; 4 – Plastic (polymer) product; 5 – Detail design; 6 – Electronic and software; 7 – Interface design; 8 – Product strategy; 9 – Industrial product
Figure 4.8 Investigation domain of industrial design application in generic modular product design and development process.
Figure 4.9 The graph shows the number of organizations that perceived the need of industrial design services in modular product design/development to meet the identified perspectives. Perspective: 1 – Aesthetic and styling; 2 – Utility and ergonomic; 3 Communication and corporate identity; 4 – Cost effective solution; 5 – Facilitate production; 6 – Product life-cycle.
Figure 4.10 This graph shows the number of companies performing industrial design in modular design tasks
Figure 4.11 This graph shows the number of companies desiring industrial design in the identified modular design tasks.
Chapter 5

Figure 5.1 Overview of InDFM mechanism’s environment

Figure 5.2 The InDFM structure

Figure 5.3 InDFM detail: formed by integration of key elements clearly shows how each element interacts within the new process environment.

Figure 5.4 Generic application detail: showing the phases (Marked by MPD’s) where industrial design (Marked by InDFM) can be accurately and systemically applied. Industrial design measures are indicated below the phase’s row.

Figure 5.5 Potential application detail: showing the synchronization of InDFM with a new product development process of a participating company.

Chapter 6

Figure 6.1 The X-Bolt, an example of the latest model of game hunting rifle made by Browning (Source: Browning.com, 2014)

Figure 6.2 FN SCAR modular assault rifle variants (FN Herstal, 2010)

Figure 6.3 FN F2000 assault rifle (top) and FN P90 sub-machine gun (bottom). Both products have elements of industrial design and product modularity in the body design (Image Source: world.gun.ru, 2012)

Figure 6.4 Armed French soldiers patrol Gare du Nord station in Paris with a FAMAS rifle, a similar ‘Bullbup’ design rifle as the F2000. (Photo source: Getty Images-AFP, 2010)

Figure 6.5 FN 303- FN rifle size less lethal weapon system components currently in the market (Image source: FN Herstal, 2010)

Figure 6.6 InDFM implementation process outline

Figure 6.7 An overview of a product development process of FN adjusted for application of InDFM – Refer to Index 4 for reference of the original proposal.

Figure 6.8 The standard design of the SCAR MK16 rifle designed and produced by FN; used for investigation of InDFM implementation.

Figure 6.9 A standard M-4 assault rifle is an upgraded derivative of the M16, commonly used by military operators since the 1960’s (Source: world.gun.ru, 2014)

Figure 6.10 An overview of the InDFM on the SCAR system product development process

Chapter 7

Figure 7.1 The configuration of the seven (7) major components of a standard M4 Carbine assault rifle

Figure 7.2 The academic research phases required to continue the work begun in the InDFM research to develop e-InDFM

Figure 7.3 A simplified interface diagram of the interaction between each attribute in the e-InDFM system
# List of Table

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Table 2.1</th>
<th>The combination of research types that are essentially used to develop the InDFM</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 3</td>
<td>Table 3.1</td>
<td>The four basic types of product innovation strategy</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Table 3.2</td>
<td>The ideal ISO 9001 activities elaborated (Source: Schoonmaker, S.J., 1997)</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Table 3.3</td>
<td>Industrial design critical outcome and objective</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Table 3.4</td>
<td>Strategic importance of industrial design (Source: Sanchez and Collin, 2001)</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Table 3.5</td>
<td>4 types of modularity typologies</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Table 3.6</td>
<td>Principles of modular design (Adopted from: Doi, 1963)</td>
<td>69</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Table 4.1</td>
<td>Mapping of sampling parameters to the survey modes</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Table 4.2</td>
<td>The details of organisations (Anonymous respondents) of various business types invited to participate in the research survey. Only 15 organisations agreed to participate in the survey</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Table 4.3</td>
<td>The number of respondents and percentage during Category I survey</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Table 4.4</td>
<td>Breakdown of responses based on the survey method</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Table 4.5</td>
<td>Five (5) main reasons from organisation for non-response in this survey – categorised by industry and region</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Table 4.6</td>
<td>The Likert-item 5 scale rating used to determine the importance of industrial design functions in strategic planning</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Table 4.7</td>
<td>The table shows the result of perceived functions requirement in the strategic product planning of participating organisations</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Table 4.8</td>
<td>Justification of industrial design involvement in generic product development process of participating organisations</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Table 4.9</td>
<td>Justification for the current and future demand of industrial designer</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Table 4.10</td>
<td>Percentage of industrial design services as recorded from the survey analysis</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>Table 4.11</td>
<td>The organisation’s need for industrial design services in modular product design/development activities based on the identified potential perspectives</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>Table 4.12</td>
<td>Actual application of industrial design in modular product design process of participating companies. The ticks in the corresponding boxes indicate the respondents are applying industrial design in the modular design tasks</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>Table 4.13</td>
<td>Desired (highlighted) application of industrial design in modular product design of participating companies</td>
<td>114</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Table 5.1</td>
<td>Key elements of InDFM taxonomy</td>
<td>119</td>
</tr>
<tr>
<td>Table 5.2</td>
<td>InDFM pre-defined codes description for implementation process</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>Table 5.3</td>
<td>InDFM pre-defined codes description for standards evaluation</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>Table 5.4</td>
<td>Detail elaborations of specific column for Checkpoint A</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td>Table 5.5</td>
<td>Detail elaborations of Checkpoint B</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td>Table 5.6</td>
<td>Detail elaborations of Checkpoint C</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>Table 5.7</td>
<td>Application of industrial design implementation table format</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Table 5.8</td>
<td>What the application of industrial design in Phase 1 (MPD 1 – Modular product definition) of the modular product design process could look like; this table represents all the five (5) activities in MPD 1</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Table 5.9</td>
<td>What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.1 – Identifying the needs</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>Table 5.10</td>
<td>What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.2 – Analysis approaches</td>
<td>133</td>
<td></td>
</tr>
<tr>
<td>Table 5.11</td>
<td>What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.3 – Needs grouping and prioritisation</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Table 5.12</td>
<td>What the application of industrial design in Phase 2 (MPD 2) of modular product design process could look like; this table is for the task MPD 2.4 – Satisfying customer needs</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Table 5.13</td>
<td>What the application of industrial design in Phase 3 (MPD 3) of modular product design process could look like; this table is for the task MPD 3.1 – Functional objectives</td>
<td>136</td>
<td></td>
</tr>
<tr>
<td>Table 5.14</td>
<td>What the application of industrial design in Phase 3 (MPD 3) of modular product design process could look like; this table is for the task MPD 3.2 – Operational and general functional requirements</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Table 5.15</td>
<td>What the application of industrial design in Phase 3 (MPD 3) of modular product design process could look like; this table is for the task MPD 3.3 – Requirement importance assignment</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Table 5.16</td>
<td>What the application of industrial design in Phase 4 (MPD 4) of modular product design process could look like; this table is for the task MPD 4.1 – Generation of product/concept.</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>Table 5.17</td>
<td>What the application of industrial design in Phase 4 (MPD 4) of modular product design process could look like; this table is for the task MPD 4.2 – Basic functional elements.</td>
<td>139</td>
<td></td>
</tr>
<tr>
<td>Table 5.18</td>
<td>What the application of industrial design in Phase 4 (MPD 4) of modular product design process could look like; this table is for the task MPD 4.3 – Basic physical components.</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Table 5.19</td>
<td>What the application of industrial design in Phase 5 (MPD 5) of modular product design process could look like; this table is for the task MPD 5.1 – System level specification.</td>
<td>141</td>
<td></td>
</tr>
<tr>
<td>Table 5.20</td>
<td>What the application of industrial design in Phase 5 (MPD 5) of modular product design process could look like; this table is for the task MPD 5.2 – SLS impact on GFR.</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>Table 5.21</td>
<td>What the application of industrial design in Phase 5 (MPD 5) of modular product design process could look like; this table is for the task MPD 5.3 – Similarity index and matrix.</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>Table 5.22</td>
<td>What the application of industrial design in Phase 5 (MPD 5) of modular product design process could look like; this table is for the</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.23 An example of verification checklist of industrial design application within each phase of the modular product design process (Eg.: Phase 1 – Product planning); this checklist may be use with the other activities in this phase.

Chapter 6

Table 6.1 Application of industrial design in MPD 1 – Modular product definiton of existing modular product design process of SWS.
Table 6.2 Application of industrial design in Phase 2 (MPD 2) of modular product design process of SWS; this table is for the task MPD 2
Table 6.3 Application of industrial design in Phase 2 (MPD 2) of modular product design process of SWS; this table is for the task MPD 2.2
Table 6.4 Application of industrial design in Phase 2 (MPD 2) of modular product design process of SWS; this table is for the task MPD 2.3
Table 6.5 Application of industrial design in Phase 2 (MPD 2) of modular product design process of SWS; this table is for the task MPD 2.4
Table 6.6 Application of industrial design in Phase 3 (MPD 3) of modular product design process of SWS; this table is for the task MPD 3.1
Table 6.7 Application of industrial design in Phase 3 (MPD 3) of modular product design process of SWS; this table is for the task MPD 3.2
Table 6.8 Application of industrial design in Phase 3 (MPD 3) of modular product design process of SWS; this table is for the task MPD 3.3
Table 6.9 Application of industrial design in Phase 4 (MPD 4) of modular product design process of SWS; this table is for the task MPD 4.1
Table 6.10 Application of industrial design in Phase 4 (MPD 4) of modular product design process of SWS; this table is for the task MPD 4.2
Table 6.11 Application of industrial design in Phase 4 (MPD 4) of modular product design process of SWS; this table is for the task MPD 4.3
Table 6.12 Application of industrial design in Phase 4 (MPD 4) of modular product design process of SWS; this table is for the task MPD 4.1
Table 6.13 Application of industrial design in Phase 5 (MPD 5) of modular product design process of SWS; this table is for the task MPD 5.1
Table 6.14 Application of industrial design in Phase 5 (MPD 5) of modular product design process of SWS; this table is for the task MPD 5.3
Table 6.15 Application of industrial design in Phase 5 (MPD 5) of modular product design process of SWS; this table is for the task MPD 5.4
## Glossary of Key Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Critical dimension</strong></td>
<td>Refers to industrial design contribution in achieving product characteristics associated with functionality, aesthetic, cost benefit, production and product life-cycle.</td>
</tr>
<tr>
<td><strong>InDFM</strong></td>
<td>Acronym of <em>Industrial Design Framework for Modular Product Design/Development</em> – the formal framework to assist integration and implementation of industrial design process in modular product design process.</td>
</tr>
<tr>
<td><strong>Industrial design</strong></td>
<td>A collective term to describe the overall creative methodology behind the planning and designing of industrially manufactured products that uses both applied art and applied science to improve the appearance, ergonomics, functionality, and/or usability of a product, and it may also be apply to improve the product's marketability and even production.</td>
</tr>
<tr>
<td><strong>Industrial design capability</strong></td>
<td>The level of competency of industrial design to improve a product appearance, ergonomics, functionality, and/or usability, and to add intrinsic value to the product. This also includes the human capabilities, time and financial resources available and exploited for industrial design.</td>
</tr>
<tr>
<td><strong>Industrial design emphasis</strong></td>
<td>A measure of industrial design, for example by examining the weight placed on industrial design related aspects in the new product design process. Industrial design emphasis has to do with a firm’s strategy to include or not include industrial design in its new product design activities, and the degree to which industrial design is included.</td>
</tr>
<tr>
<td><strong>Industrial design management</strong></td>
<td>A structures and practices set up to deploy industrial design, and to deliberate strategies for optimising industrial design’s contribution to performance.</td>
</tr>
<tr>
<td><strong>Industrial design measurement</strong></td>
<td>The operationalisation and integration of industrial design capability, emphasis, and management throughout the new product design process.</td>
</tr>
<tr>
<td><strong>Industrial design outcome</strong></td>
<td>This is defined as the exhibited industrial design characteristics of a product, service or firm. Industrial design outcomes are not a</td>
</tr>
</tbody>
</table>
measure of amount but rather a measure of goodness.

**Framework**
The developed framework known as *InDFM* – a combination of design processes and implementation standard used to optimise the application of industrial design, review, and maintenance in modular product design in accordance with the best practices.

**Standards**
Industrial design benchmark that should be follow to maintain the credibility of the framework implementation.

**Systematic methodology**
A new industrial design methodology that is structured by integration of the ISO9001 design process, and industrial design operationalisation aspects, that is used to optimise industrial design in modular design process.

**Systemic approach**
An approach that is universal for implementation of industrial design methodology within a modular product design process.
Chapter 1

1. Introduction

Objective: This chapter provides:

- Background and interest in industrial design framework for modular product design.
- Aims and objectives addressed by this thesis.
- A guide to the research approach taken and the structure of the thesis.

1.1 Background

This thesis looks into the industrial design methodology and its potential to support design and development needs in product modularisation. The main aim of the research had been to develop and to introduce a systematic approach to optimise industrial design innovation in modular product design through the application of a new universal framework. The development of this framework had been the primary focus of this research.

Product organisations, such as Apple, BMW, Logitech, and Tefal, have been successful mainly due to their emphasis on industrial design. These organisations have made design a priority than technology in their strategic product development plan (Turner, 2007; Masson et. al., 2010). However, a majority of similar organisations have failed to recognise the potential of industrial design in creating more innovative product that could actually provide them with an edge in the highly competitive product market. Generally, the approaches taken by these organisations have been ad hoc or localized, thus leaving them to embark on disorganised design process management both on the product itself, as well as the process flow (Bruiyan, 2011; Candi and Gemser, 2010; Sanchez, 2002). Most often product design and development is considered as a process for creating functional differentiation through superior performance and added features of a product. This idea, however, is changing today as industrial design is increasingly being seen as an important strategic tool in creating preference and deeper emotional value for the consumer (Masson et. al., 2010; Melles and Kuys, 2010; Mostowics and Grzecznowska, 2004). Besides, the product design process is a highly complex set of integrated efforts that involve idea generation, concept
development, assessment and revision of details, as well as evaluation for appropriate solutions. The complexity of this process increases in modular product design as the decomposition of the product into modules creates a dedicated process for each module. Thus, the ad-hoc approach to the implementation of industrial design to products with complex architectures, such as those that demand a modular approach, has highlighted deficiencies, particularly in aspects of design process management. Additionally, the dynamic nature of product development suggests that a systematic and holistic approach, rather than a localized one, in the application of industrial design is required.

Therefore, in order to address these concerns, this research proposed a new *Industrial Design Framework for Modular Product Design (InDFM)*. The application of InDFM is supported by a defined and comprehensive technical standard document that is essential for successful application of the framework. Moreover, the focus of this framework is the guidance of modular product organisations in taking a more methodical approach to industrial design application in their modular product design and development projects, not only on the design aspects of industrial design, but also the overall operationalisation of industrial design. With the application of the new framework, it is anticipated that the final outcome would be a modular product that is more innovative and creative in the overall design and development context.

### 1.2 Motivations

A shift in competitive environment has forced many companies to diversify from the standard mass-market products into variations of similar products or mass-customisation (Kratochvil and Carson, 2005). Thus, the concept of modularity (Sanchez, 2002; Baldwin and Clark, 2000; Kamrani and Salhieh, 2000; Ericsson and Erixon, 1999) was introduced. On top of that, the growing number of global product companies is now not only adopting modularity, but also adopting new kinds of design strategies and implementing new development processes (Sanches, 2002) that are explicitly focused on achieving a range of competitive advantages through modular product design. However, an initial review of the literature in the area shows that the current approaches to modularity are largely the domain of engineering designers and there is little to suggest that the potential role of industrial design within the modular product development process is recognised. Therefore, it is
assumed that researchers and product organisations have failed to perceive the strategic importance of the industrial design method within the modular product design process. It is also assumed that in many product development processes, industrial design has rarely been described as an important element that contributes to the strategic planning programs of a product-focused organisation.

In addition, the industrial mainstream tends to perceive the industrial design as a source of aesthetics and rarely as a major contributor to the sales proposition (Candi and Gemser, 2010). In reality, industrial design provides critical visual and tactile elements, which are the ultimate influence, both on immediate sales and on total customer experience over the lifetime of a product. Moreover, the influence of industrial design is unrestricted as industrial design services can be applied to most industries (Ulrich and Eppinger, 2000). In fact, the application of industrial design within product development processes has become essential and is rapidly being recognised as one of the important strategic tools in product development. However, applying industrial design in a modular product design process is a complicated task that requires a precisely defined approach. Besides, a number of research studies have been conducted on modular product design, such as the development of an integrated methodology of modular product design (Asan, Polat and Serdar, 2004). This methodology contains additional tools and stages for a complete modular architecture design, in which the boundaries of the modular design process are widened by adding strategic issues, appropriateness to modularity, degree of modularity, and strategies of modularity. Integrating industrial design and modular product design processes is basically creating interdisciplinary collaboration between industrial designers and engineers since product modularisation is within the domain of engineering design. The interdisciplinary collaboration could provide better solutions to product design and development issues through complementary knowledge of different experts, whereby improvements can be made easily, and new common knowledge can be developed (Wang et. al., 2009; Rossi et. al., 2009). Meanwhile, another study explored product modularity optimisation (Arnheiter and Harren, 2005), whereby each type of modularity was characterised by a different set of design attributes. Attributes, such as appearance, durability, and ergonomics, are all important for product-use modularity, while accessibility, recycling, and cost are key considerations for limited life modularity. All these attributes can provide a product with a competitive edge in the marketplace. Furthermore, the optimisation approach requires a comprehensive understanding of the different modularity characteristics by designers and it is crucial to
design products that address relevant customer needs, such as customization, cost, serviceability, and upgradeability.

An example of a successful application of the industrial design in modular product design is highlighted by *Philips Electronics* with its series of electric shavers (Refer to Figure 1.1). The company has demonstrated in its product family that industrial design indeed played a critical role in providing spatial styling variations while maintaining the same degree of user interaction and ergonomics. Industrial design in products, such as those illustrated, provides some of the few critical differentiators in developing compelling, and globally competitive brand propositions (Juratovac, 2005; Mostowics and Grzecznowska, 2004).

![Figure 1.1 - Philips electric shaver series (Philips Electronics, 2010)](image)

### 1.3 The Need

The issue of under-utilised potential highlighted in industrial design for modular product design process had prompted this research into a systematic framework to utilise its full potential in order to achieve highly innovative and creative modular product values. Modular product design and industrial design are two design approaches that are familiar with most product organisations today, but unfortunately, there is relatively little documentation or records of integration pertaining to these approaches, and thus, has led the researcher to believe that they have not been studied in any great detail. The initial literature investigation to this research has indicated that there is a significant need to develop an approach to integrate and to optimise industrial design in modular product design as a
growing number of global companies have now adopted modularity concepts in managing the technical development of their new products. Thus, this indicates an increasing need to develop a specialised industrial design approach to facilitate modular product designers in enhancing the innovative values of their product designs. In relation to this, Sanchez and Collins (2001) had suggested that industrial design should be utilised as a cost effective approach to innovation in design, particularly in the context of engineering design. With that, industrial design could be an important strategic tool in developing modular products. The proposed systematic framework for industrial design is also a generic framework, which can be applied in any modular product design. Based on this notion, the strategic importance of the industrial design framework for modular product design can be perceived as in the following:

1. The need to develop design concepts for more extensive product lines in order to increase product variety.
2. Refreshing product designs through styling changes in visible components for technologically mature modular products.
3. An essential role in modular product strategies by creating styling variations that can effectively distinguish individual product models within a modular product family.
4. Helping to bring a series of technologically upgraded products to market in rapid succession.
5. Providing effective differentiation of new product models by stylization in order to communicate visually the improved technical performance of the new product.

Further details on the strategic importance of industrial design in design for modularity are described in Section 3.1.6.1, Chapter 3 of this thesis. It should be stressed that the increasing interest for industrial design is an interesting symptom of changes not only in modular product development, but also in the overall product development environment (Le Masson, Weil & Hatchuel, 2010).

1.4 Aims and Objectives of Research

The research accomplished three (3) significant outputs – Framework, Methodology, and Principle.
1. **Framework** – To investigate and to analyse the framework proposed for industrial design and its adaptation to design for modularity in the context of product design and development as a holistic process.

2. **Methodology** – To develop a formal industrial design framework for modular product design as a structured methodology for industrial design optimization and process integration in modular product design process management.

3. **Principles** – To investigate, demonstrate, and validate the underlying principles of InDFM through field trial analysis, as well as to model its characteristics and processes.

In addition, the research achieved the followings objectives in relation to – **Need, Nature, Methodology, Framework Model, and Principle**.

1. **Need** – **Investigate the need for application of InDFM**
   - Identify opportunities for InDFM research.
   - Develop industrial case studies across a range of company sizes and industries.
   - Clarification and justification of the business drivers that industrial design in modularity can address.
   - Identification of general and specific needs for an industrial design approach.

2. **Nature** – **Clarify the nature of industrial design framework for modular product design**
   - Review the existing work on industrial design and modular product design, as well as how they relate to the domain.
   - Define the meaning of industrial design and modularity.
   - Determine the advantages and the flaws of InDFM.
   - Investigate the applicability of industrial design and design for modularity.
   - Highlight the need for a structured approach for product realization and the specific impact of InDFM on research, design, development, and the user.

3. **Methodology** – **Develop a methodology for InDFM**
   - Structure the amorphous area of industrial design within a methodology for application.
   - Consider its application to a range of companies, modular products, and services.
   - Provide the details of the methodology for InDFM by addressing target, implementation, and maintenance.
4. **Framework Model** – Investigate industrial design as the main component of InDFM

- Review industrial design and investigate its neglect as integrated process of modular product design.
- Develop an industrial design based framework for InDFM methodology.
- Acknowledge the InDFM and its processes as a system, including the possible implications it has.

5. **Principles** – Demonstrate and evaluate the methodology of InDFM.

- Investigate the underlying principles of InDFM that apply regardless of application format or circumstance.
- Determine processes and measurables that provide insight into the key elements of InDFM.
- Document and analyse case study experiences.
- Solicit feedback from the industry pertaining to the InDFM methodology.
- Model the influence of InDFM upon product realization.

### 1.5 Scope of Research

Figure 1.2 – The generic processes applied in design and development of new product (Adopted from: FN Herstal, 2007)
Product organisations generally apply the generic process in new product design development with adaptation to the type or category of the product to be developed (Kenneth, 2013; Bruiyan, 2011; Krishnan and Ulrich, 2001). Moreover, several processes or methods are available, and although industrial design plays vital role in design process modelling, structuring, and management; product organisations somehow have overlooked their contributions from the perspective of modularisation. Nevertheless, in the generic product design processes (Several examples are as shown in Figure 1.2), it is difficult to distinguish the stages of the design and if the development processes are the potential or appropriate points of industrial design. As observed from the examples, the implementation of a new product requires a series of activities, which consists of several main phases such as idea generation, idea screening, concept development and testing, marketing strategy, business analysis, product development, test marketing, and commercialization. The more innovative the product is, the more complicated is the process (Chwastyk and Kołosowski, 2013; Hussein et al., 2014), and the decomposition of components into modules in modular product development further complicates the whole process.

![Figure 1.3 - The research scope](image-url)
The research into developing and establishing a new dedicated framework is expected to facilitate the integration of industrial design in modular product design process. The development of the framework encompassed several important areas (Refer to Figure 1.3) as the researcher investigated, understood, and analysed the relevant areas, including holistic product development processes, product architectures with emphasis on modular product architecture, industrial design methodology, operationalisation theory, and modular product design process.

1.6 Focus of Research

The application of the new framework is vital in the industry sector as the potential of industrial design is currently less noticeable and generally ignored, such as the defence and security sector, as well as the industrial machineries sector. The products of these industries are mostly developed according to integral architecture, thus, the product design process is dedicated to a specific product. A new design process is then needed for another product, even if the product is from the same family line. In relation to this research, the researcher focused on the benefits of industrial design intervention, accessibility, and opportunism in design development for the defence and security sector. This sector was chosen in view of the fact that the products are designed with user-centred consideration.

![Figure 1.4 - The Sturmgewehr 44 (StG 44) firearm, generally considered as the first assault rifle that served to popularise the concept and form the basis for today's modern assault rifles.](image)
Furthermore, the competition in the market for defence products, in particular the assault rifles (Refer to Figure 1.4), is intense and the industry players are turning to modularisation strategy to seek cost effective and rapid product turnaround advantage. The modularisation strategy in producing more variants of product is increasingly accepted to counter the competitions. On the basis of this actuality, the researcher outlined the rationales for the selection of this industry as the foundation of this research. The rationales are depicted in the following:

1. **Mature Technology Product**
   The personal weapon systems – this research typified the system as assault rifle technology. Assault rifle is considered as a mature technology product as it has been in use for long enough periods that most of its initial faults and inherent problems have been removed or reduced by further development. The concept of the assault rifle started in the early 1910s, initially an improved design of the traditional rifle with a small-bore selective-firing system complete with detachable box magazine (Lewis, 2004; Senich, 1987). As the technology is mature, most of the advances are slight improvements as manufacturers alter feasibility factors, such as product-user interaction, balances between weight, firepower, range, and accuracy. Besides, the improvements of the design are mostly engineering-based and the industrial design process is basically non-existential, therefore, there is a need to develop a formal industrial design process theory for this sector.

2. **Traditional Design Strategy**
   ‘Do not repair if it is not broken’ is the typical norm when mentioning a product that has worked really well in performing its tasks. Improvement of the product is very minimal as the product is largely static since there is little market demand for change (Freeman, 1987). Innovation and advancement are limited to minor product changes in order to make to overall production more cost effective. With that, the most obvious innovations to the assault rifle are the addition of auxiliary parts, such as optics, and attached secondary ammunition device to add more precision and firepower to the rifle. These are the vital areas where industrial design plays its vital roles to facilitate the consolidation of new components with the existing rifle design through industrial design innovation.
3. **Product Variation**

The assault rifle is currently competing very stiffly in the defence market. Many nations are downsizing the size of their military personnel and moving towards computerised high technology weapons, which are cheaper to operate in the long run. Cuts in military spending are inevitable as nations focus on strengthening its economy (Friedman and Preble, 2010). At this stage, competition on the basis of price is getting fierce. With so many product variants available, the selling price highly depends upon how lean and efficient the production engineering could go. In addition to this, the availability of auxiliary components also plays an important role in adding advantageous value to the product. Looking at the situation, most product companies would choose to invest in advanced engineering processes rather than industrial design since these processes are readily available. Although the importance of industrial design for innovation management has been proven (Dell’Era and Verganti, 2009), industrial design process has not been used strategically to enhance the innovative features of the product.

4. **Product Differentiation through Innovative Value**

The addition of extra components to the rifle body design does not necessarily constitute to better value that differentiates competing products in the market. Extra components may add more functionality and extra performance, but they definitely add extra cost not only in terms of procurement budget, but also training and maintenance. Hence, the researcher believes that the recent trends in adding ‘creativity phase’ (Candi and Gemser 2010) before the design and development process could increase the innovative value of the product. Moreover, innovation has been commonly perceived as restricted to technological innovation where the actors involved are researchers and engineers from the R&D department. Besides, innovation in mature technology product, such as assault rifle, is very limited, and thus, injection of creativity into the design of product user interaction, feasibility, communication, and semiotics could provide significant differentiators critical in maintaining the advantage.

Based on the rationales, the researcher believes that studies that combine technology and creative innovation in modular product design process have not been done in any great detail. Creativity has been applied in an ad hoc manner where there is no specific methodology to organise and manage the process. In addition, the process of applying industrial design in modular design process requires a cross functional team who are
unfamiliar with each other’s expertise, and in recognising a design as a conscious activity (Alvarez and Martinez 2011), the design activities of the teams must be organised and managed systemically through a formal framework.

1.7 Thesis Outline

The writing of the research thesis was carried out based on the research stages, which are also referred as Chapters. For the purpose of this research, the researcher has established eight (8) Chapters. These chapters are described in the following:

- **Chapter 1-2** – *Articulation and background of the research*
- **Chapter 3** – *Investigations and analyses of the research subjects within the research domains*
- **Chapter 4** – *Defining the research findings*
- **Chapter 5-6** – *Development and assessment of resolution based on the research findings*
- **Chapter 7** – *Instigation of further discussion, summarising the research effort, and suggestion on future improvement of the research work*

The thesis is structured to reflect the approach adopted – providing and investigating background through the literature, developing the need through real time observations, consultations and collaborations with industries, analysing the opportunities InDFM present in meeting these needs; developing a structured response to the need that reflects the broader issues of industry; and finally, evaluating the opportunity and the application of the process as demonstration of its effectiveness.
Chapter 2

2. Research Methodology

Objective: This chapter provides:

- The description for selection of the methodology applied in conducting this research.
- The characteristics of the applied methodology.
- The description of the applied research methodology phases.
- The approach taken in reviewing the related literatures.

2.1 Methodology Characteristic

The nature of this research required the researcher to be involved within the modular design and development process environment of product organisations. Involvement within a process environment inclined the researcher to adopt either immersive research (Corrêa et al., 2010, Apostolopoulos et al., 2012) or action research (Greenwood et al., 2007, Reason and Bradbury, 2001, Jacob et al., 1992) approach for the purposes of strategizing a solution for the industrial design issues (Refer to Chapter 1, Section 1.1), and developing guidelines for the best practice within that process environment. After considering several factors relating to immersive research, such as the researchers’ lack of experience in using the approach, limited understanding of the tools used, limited skills in immersive technologies, and limited communications skills within the immersive environment, the researcher had decided to drop the immersive research approach.

Therefore, the latter had been chosen based on its practicability and holistic approach in data collection and analysis, plus the added advantage of the researchers’ familiarity with the approach. The practical action research approach in the context of this research is further described in the next sections.
2.1.1 Action Research

A practical action research approach is characterised by four (4) fundamentals (Jacob et al., 1992), which are described below. The descriptions are within the context of this research.

1. **Research problem** – This research focused specifically into the integration of industrial design in a modular product design and development process. In this context, the action research was aimed at tackling issues of implementing industrial design in modular product design process by product developers through the use of a new defined approach in the form of the proposed formal framework and guideline (standards) documents. The new approach was finalised and applied in actual practice where it was evaluated and validated.

2. **Collective participants** – The participants, in the case of this research, included the researcher, product organisations, product design and development consultants, as well as related academicians and experts. They formed an integral part of the research with the exclusive aim to collaborate in providing valuable inputs for structuring the framework proposal. The participants of this research had been specifically selected based on their product and services, which were considered to be associated with industrial design and product modularity concept.

3. **Type of empirical research** – The action research approach is characterised as a means to change the practice while the research is on-going. Therefore, throughout this research, solution proposals were worked out by the participants and were discussed to evaluate the practicability of the solutions. For the purpose of this research, a new framework was applied to an existing or a new modular product design and development process of participating companies. The outcome of the application was analysed for further development and improvement.

4. **Outcome of research** – The outcome of the whole research cannot be generalized. The outcome of this research is a new methodology that is anticipated to solve the issues identified within the researched domains. The methodology must be seen as a renewed corrective action and should comply with the scientific criteria set by the collaborating groups of participants.
2.1.2 Strengthening the Action Research

In order to strengthen the action research, and after a series of thorough reading and understanding of the available methodologies, the researcher decided to apply one of the *triangulation methodologies*. The triangulation methodology is a method used by qualitative researchers to check and establish validity in their studies by analysing a research question from multiple perspectives (Stake, 2010; Olsen, 2004; Golafshani, 2003; Jick, 1979). The advantage of the triangulation methodology is its holistic approach to problem solving by using multiple research approaches, rather than a single method or theory for collecting and analysing data. Generally, there are five (5) types of triangulation methodologies, which include:

1. **Data triangulation** – different sources of information are used in order to increase the validity of a study. This type of triangulation is most commonly used because it is the easiest to implement and is particularly well-suited for extension given the different stakeholder groups that have vested interest in the research.

2. **Investigator triangulation** – more than one investigator are involved in the analysis process. The findings from each investigator would then be compared to develop a broader and deeper understanding of how the different investigators view the issue. This is an effective method of establishing validity; however, it may not always be practical to assemble different investigators given time constraints and individual schedules.

3. **Theoretical triangulation** – multiple perspectives are used to interpret a single set of data. This method usually involves professionals outside of a particular field of study as professionals from different disciplines offer different perspectives. Therefore, if each evaluator from the different disciplines interprets the information in a similar manner, then validity is established.

4. **Methodological triangulation** – involves the use of multiple qualitative and/or quantitative methods. The results from surveys and interviews are compared to identify similarities, and if there are, then validity is established. While this
method is popular, it generally requires more resources and time to analyse the information produced by the different methods.

5. **Environmental triangulation** – entails the use of different locations, settings, and other key factors related to the environment in which the research took place, such as the time, day, or season. The key is identifying which environmental factor, if any, might influence the information that is received during the research. These environmental factors are changed to see if the findings share similar settings. If the findings remain the same under varying environmental conditions, then validity is established.

Out of the five (5) types of triangulation methodologies mentioned above, the researcher chose to adopt the *methodological triangulation*. The selection of this type benefitted the researcher by increasing the researchers’ confidence in the research data, as well as in facilitating clearer understanding of the research problem through diversity and quantity of data that were used for analysis. Moreover, the selection of methodological triangulation also allowed the researcher to apply various different research tools throughout the duration of the research, such as keeping a research journal, collection and analysis of literature documents, as well as investigation and surveys through questionnaires and process observations. Other tools, such as structured and unstructured interviews and case studies, were also employed. Therefore, the use of a variety of additional tools should add some depth to the results that would not have been possible with single-strategy study; thereby increasing the validity and the utility of the findings. However, the researcher was also aware that the application of this type of methodology has some disadvantages, such as the requirements for greater planning and organisation, and not to mention, very time-consuming. Nevertheless, these disadvantages were exploited to develop better discipline and self-control to the researcher, particularly throughout *Phase 1* and *Phase 2* (Refer to Figure 2.1) of the research process. The results obtained from the research should be relevant to the actual practices and applicable for development of *InDFM* immediately. This research took a total duration of a minimum three (3) years for completion.

The following table (Refer to Table 2.1) describes the combination of qualitative and quantitative methods used in the methodological triangulation for this research.
<table>
<thead>
<tr>
<th>Approach</th>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPERIMENTAL</td>
<td>Quantitative</td>
<td>Researcher separates and controls all relevant conditions that determine the event investigated, so as to observe the effects when the conditions are manipulated.</td>
</tr>
<tr>
<td>EVALUATION</td>
<td>Qualitative</td>
<td>Responsive evaluation – a series of investigative steps is undertaken in order to evaluate how responsive the newly developed framework is to all those taking part in it.</td>
</tr>
<tr>
<td>ACTION</td>
<td>Qualitative</td>
<td>Research is carried out in the real world rather than in the context of a close experimental system.</td>
</tr>
</tbody>
</table>

Table 2.1 – The combination of research approaches in methodological triangulation that are used to develop the InDFM

2.2 Individual Research Context

The actual research process applied in this research (Refer to Figure 2.1) had been based on the selected triangulation methodology. Five (5) major phases had been determined, as listed in the following:

1. Research Articulation
2. Investigation Survey
3. Development
4. Finalisation
5. Writing of Thesis

The overview of the stages is described in the following sections.

2.2.1 Research Articulation

The decision to research the topic was based on the researcher’s experience in the industrial design service. The topic was chosen as the researcher had identified that there is no systemic approach to implement industrial design operationalisations in modular product design and development. The abstract and a brief research proposal were presented and discussed with the research supervisor and the director for approval. After the research proposal was approved, literature search and reviews on the related domains were conducted.
This task began with an initial review of industrial design process and specific stages in order to fully understand its generic methodology and the intended goals. In addition to industrial design, the modularity concept, as well as the relevant process of modular product design and development, was also reviewed. Preliminary investigation into the current industrial design and design for modularity state of affairs were conducted through qualitative method in order to manifest a theory of the research issues.

Figure 2.1 – Overview of the actual (Individual) research phases based on triangulation methodology used in the development of InDFM
2.2.2 Investigation Survey

Emphasis was made on the perceived importance of industrial design operationalisations and functions, including strategic inputs and key roles in standard product design and development processes, across a broad range of industries. The approach taken in the investigation survey had been based on empirical strategy with emphasis to cross-sectional surveys (Babbie, 2010). The surveys were conducted through several methods, which were mainly qualitative. Case study and field study were conducted with modular product and service companies in the United Kingdom, Western Europe, and South East Asia for the purpose of identifying when and where industrial design was utilised in the companies’ design and development processes. The details of the adopted investigation survey are described in Section 2.4 of this chapter. The findings of the investigations were used to formulate a new framework model with the associated technical guideline (Standard) documents.

2.2.3 Framework Development

The new framework is called InDFM, which is the abbreviation of Industrial Design Framework for Modular Product Design/Development. The development of the framework was done concurrently with the guideline standards that were used to elucidate the implementation of the framework. In addition, progress assessments of the framework and the guideline standards were conducted throughout the development before finalization. The development of the framework started with the establishment of the framework structure. The structure elements consisted of industrial design measures or operationalisation, industrial design process, conceptual and existing modular product design processes, as well as modular design principles. Next, the integrated process of industrial design and modular product design was then either adopted as a new process, or incorporated as an enhancement tool into an existing process.

Implementation of the new framework into a modular product design process had been supported by defined guidelines standards. These standards were developed to provide an appropriate and practical approach for optimising industrial design within a generic modular product design process based on the core activities within each phase. Each standard
was presented as a checkpoint table for reference. The checkpoints used in these standards enabled the user to determine and to respond to the requirements needed in order to accomplish the industrial design inputs tasks. These checkpoints also facilitated the user in establishing the fundamental objectives of implementing industrial design in their design and development process by providing a breakdown of subjects that needed prior consideration.

2.2.4 Framework Finalisation

The finalisation of the framework involved a process known as feasibility evaluation. Evaluations were conducted on the final InDFM model. The overall purpose of the final evaluation process was to determine if the developed framework met the requirements and the needs of the industries. The evaluation outcomes resulted in assessment of InDFM feasibility to successfully accomplish its intended goal.

The InDFM model was presented to selected organisations that designed and developed products of related category. The evaluation was conducted on InDFM application on a conceptual modular design process. Nonetheless, the evaluations on the application of the framework on actual and ongoing processes were not conducted as product development process duration, which normally takes from several months to years to be completed. This is also due to the fact that a new product development is a classified project and that product organisations had been reluctant to disclose the details of their process.

Moreover, the evaluations of the InDFM process feasibility had been based on predetermined criteria set to meet the framework specifications. The evaluation criteria used to assess the InDFM consisted of both factors and sub-factors that reflected the areas of importance to the participating organisations’ processes. With the evaluation factors, the organisations were able to assess the similarities and the differences, plus strengths and weaknesses of the InDFM in comparison to the existing process that they currently used. The evaluation criteria also consisted of the following compulsory aspects:

- Reflect the needs of the organisations and facilitates preparation of improvements that best satisfy those needs.
- Provide for an accurate evaluation of the InDFM.
- Represent key areas of importance and emphasis to be considered in the evaluation decision.
- Support meaningful discrimination and comparison between the InDFM and the existing design and development process.

On top of that, the participating organisations evaluated the InDFM based on the criteria provided in an evaluation form (Refer to Index 3). The evaluation results were used in making decision on accepting the implementation or the integration of the InDFM to the current process employed by the organisations. Moreover, publications on the theory of the framework were also carried out, while the overview of the research had been presented in a number of workshops, seminars, and conferences proceedings to instigate discussions and receive feedback from academic and industries pertaining to the framework.

With the application of the triangulation methodology, the convergence of several research methods helped in providing greater confidence in the applicability of the results. Besides, validation of the InDFM was conducted for the sole purpose of demonstrating and documenting that its theory and process functioned effectively. The InDFM process validation was aimed to ensure and to provide documentary evidence that the process was capable of consistently producing the intended outcome of the required quality. The outcomes of the InDFM evaluation were used as evidence for the validation process. Evidences for the validation were also acquired from the development process of the InDFM. As anticipated during the development stage, the researcher managed to gain sufficient information about the InDFM process, while discussions on the feasibility of the process were done on various stages of the development with the participating organisations. In addition, the product development managers (or relevant personals) were selected to conduct the validation of the new process. The validation process had been based on the analysis carried out by the product manager and his overall perceptions of the InDFM. The outcomes of the validation were purely descriptive, and hence, the approach was categorised as phrase validation. Besides, a set of guidance document on process validation was adhered to. As the InDFM is a newly developed framework, no validation standard had been available to be adhered to or used as a benchmark. Therefore, the application of triangulation and action research methodology allowed for the confirmation of findings through convergence of different perspectives where the point at which the perspectives converged had been seen to represent the actual situation.
The outcomes of the validation were noted and recorded for further improvement of the framework. All results from the evaluations and validations were revised and recorded to facilitate future research in the area.

2.3 Literature Review Approach

A literature review is an account of what has been published on a topic by accredited scholars and researchers (Fink, 2010).

The main purpose of conducting literature review for this research was to seek a guiding concept in defining the research objectives. It is also an important approach to increase one’s knowledge bank about the topic being researched by seeking information through manual or computerised method for related and useful research in journal articles and publications. As the scope of the research involved product development processes, industrial design, and modularisation concept, it had been important to identify research articles related directly to and within the scope. However, the researcher assumed that little research has been done in the area of integrating the specified fields. Therefore, the literature search was preceded further beyond the scope to encompass conceptual and new product development process, product design and architecture, mass customisation, as well as other approaches in competitive product development and manufacturing.

2.3.1 Related Research Articles Search

As stated in Chapter 1, the researcher believed that the strategic involvement of industrial design in new product development process has not been widely researched. Information regarding the involvement of the industrial design discipline or operationalisations in the modularisation concept has been minimal. Moreover, the perceptions that industrial design is just a source of ‘pretty boxes’ and not a major contribution to sales proposition (Desbarat, 1994) by most product organisations can be seen as the major cause of the situation. Besides, a limited number of researchers have published materials concerning the integration of industrial design and modular product design (Sanchez, 2000; Collin, 2001). Additionally, the literature does not cover the topic in-depth.
Therefore, in order to acquire comprehensive literature coverage of the topic, review of the literature had encompassed a wider scope of product design and development with emphasis on methodologies and processes. On top of that, review of a broader category of industrial design and modular products was also carried out before identifying a specific modular product that would be used as the focal point of the InDFM development.

The initial step comprised of reading articles from related books, journals, and periodicals in order to build fundamental knowledge of the research topic. For a more up-to-date-readings, articles from journals and conference papers that are relevant to the research topic formed a crucial part of this stage. The next step of the literature search comprised of a web-based search via Google and other internet search engines; MetaLib (Refer to Figure 2.2), electronic journals and books, as well as the Loughborough University Online Public Access Catalog (OPAC). The majority of the relevant research articles for this research had been acquired from Science Direct (Refer to Figure 2.3), which is one of the preeminent subject browsers available through MetaLib. Some core subjects provided by Science direct

![Figure 2.2 - ScienceDirect subject browser (ScienceDirect, 2008)](image-url)
are physical sciences and engineering, life sciences, health sciences, as well as social sciences and humanities.

All the literature and information acquired through these sources were catalogued and stored in databases. *Refworks* is one of the methods provided by the Loughborough University for this purpose. *Refworks* is used as web-based bibliographic database management software. The outcome of the literature reviews is detailed in the following chapter (Chapter 3).

![MetaLib search page](image)

Figure 2.3 - MetaLib search page (Loughborough University, UK, 2009)

### 2.4 Investigation Methodology

The methodology adopted for the analysis had been based on *serial surveys* (Lesley, 2012; Babbie, 2005; Denzin and Lincoln, 2005). Serial surveys are survey methods conducted through repetitions of similar questions at different points in time and producing repeated measures data. There are three basic designs for serial surveys – *cross-sectional,*
longitudinal, and time-series (Rubin & Babbie, 2013; Babbie, 2005; Denzin and Lincoln, 2005). The following depicts the general description of the survey methods.

1. **Cross-sectional surveys** – use different units (respondents) at each of the measurement occasions by drawing a new sample each time. The time intervals may be different between measurement occasions, but they are the same for all units (respondents). A study in which a survey that is administered once is also considered to be cross-sectional.

2. **Longitudinal surveys** – use the same units (respondents) at each of the measurement occasions, by re-contacting the same sample from the initial survey for the following measurement occasion(s), and asking the same questions at every occasion. The time intervals may be different between measurement occasions, but they are the same for all units (respondents).

3. **Time-series surveys** – also use the same units (respondents) at each of the measurement occasions, but the difference with longitudinal study designs is that in time-series designs, both the number of measurement occasions and the time intervals between occasions may be different between units (respondents).

The surveys were conducted through several methods (modes), which were mainly qualitative. The core methods consisted of questionnaire distribution, semi-structured interview, and actual location visits. These survey methods were repeated with the same sets of questions and measurements within the methods at different points throughout the investigation period. For the purpose of this analysis, the *cross-sectional survey* method had been emphasised. The survey was designed to allow the use of different sample units (respondents) at each measurement period. This means, different groups of respondents could be approached during the survey period and the results from these groups had been applicable. Although the questions and the measurements set had been similar, the time interval between the measurement periods was different. The surveys were conducted continuously within a pre-determined time frame throughout the research period. The following sections describe the preliminary planning of the investigations based on the method chosen.
2.4.1 Investigation Set-up Structure

The initial task conducted prior to the investigation was to set up the methodology structure that had been adhered to throughout the investigation period. The structure mechanisms consisted of several important elements (Refer to Figure 2.4) that formed the fundamental of the tasks. The methodology structure was set up with the objectives of facilitating the overall investigation process and establishing the investigation inferences. The elements of the methodology structure are described below.

Figure 2.4 – Investigation methodology design set-up structure

The structure of the methodology began with planning and establishing the primary questions that leveraged the survey investigations. For the purpose of investigation in this research, it was decided that the most appropriate methods were questionnaire, semi-structured interview, and visits to the actual location. The design of these methods took into account the target scope of the investigation. Moreover, the decision on the survey parameters was made based on the information acquired from sources, mainly in the form of design and engineering practitioners, design and engineering journals, such as the International Journal of Technology and Design Education, published by Kluwer, Journal of Mechanical Design published by ASME, and other related publications, such as the International Journal of Design, published by Creative Commons, and The Chinese Journal of Mechanical Engineering, published by Tsinghua Tongfang Knowledge Network.
Technology Co. Ltd. from Beijing, China. These sources contained information specifically relevant or related to industrial design and product modularity theories. The information on the current issues derived from the application of these theories had been important to establish the target scope and primary question needed for the investigation. For the purpose of this research, the scope of the investigation was primarily targeted at modular product designers and developers, industrial design services providers and consultancies, in-house practitioners, as well as product organisations and manufacturers. The selection of these samples (respondents) was judged by intensive examination of the types and the category of products or businesses they were involved in. Meanwhile, the countries and the regions of the investigations are described below.

- **England (United Kingdom)** – The survey locations were within the proximity of Loughborough University, the base of the researcher. The selection of this region facilitated logistics throughout the research duration. Surveys conducted within this region involved product and industrial design organisations, research and development organisations, as well as design consultants.

- **Belgium (Western Europe)** – This had been the location of one of the world’s most renowned weapon manufacturer, FN Herstal, developer and manufacturer of some of the most used rifle brands, such as Colt M16 and Browning. The research on product modularity, which focused on modular rifle systems, convinced the researcher that the selection of this product organisation would provide vital design data to complete this research.

- **Malaysia (South East Asia)** – The design philosophy of Asian product organisations differed from those in the European region, particularly in regard to perceptions and appreciation of industrial design values as cost effective approach to product innovation. The differences in the design philosophy lead to emphasis on product feasibility rather than both feasibility and aesthetics (Alvarez and Martinez, 2011). Aesthetics values are normally linked closely to localised traditional design values (The Disneyland Report, 2012). The selection of this region facilitated in the comparison analysis of industrial design process validation.

Please refer also to Chapter 4, Section 4.2 for further description and explanations of the sampling parameters (criterion) for selecting the samples. The primary questions had been
based on the generic processes of modular product design and the application of industrial design within the process.

2.4.2 Implementation

Before the implementation of each method had been carried out, an investigation plan was devised. The investigation plan was strictly based on the primary investigation objectives. Therefore, the principle of the investigation plan was directly aimed at identifying and achieving these objectives. The primary objective of identifying the actual needs and practices of industrial design required several sets of questions that had been directed at modular product organisations, as well as industrial design consultants and practitioners. Besides, the primary objective of identifying the actual impact of industrial design within the modular product development process was directed mainly towards modular product organisation, which included modular product developers, and producers or manufacturers. The intended respondents were identified and selected based on the products that they developed or produced. These respondents were contacted and informed about the intention and the purpose of the investigation. The respondents were also enlightened on the potential benefits that they might receive from the research. In addition, correspondences with the respondents had been conducted via electronic mailing system (e-mail) and telephone. Courtesy visits were also conducted where possible. The responses and feedback from the intended respondents were anticipated to gather the results that were needed to outline the foundation of a new method of applying industrial design in modular product design and development. Furthermore, interview appointments were also planned with key product design and development personnel of the organisations. Other than that, facilities and factory visits were also planned for the purpose of conducting observation tasks. However, due to the profound nature of business carried out by some of the respondents, it had been anticipated that some of the respondents might decline the researcher’s request for facilities or factory visits.

The completed sets of investigation documents containing the approved questions were distributed during the investigations. For the purpose of this research, a total number of 55 respondents (products and services organisations) had been contacted and invited to participate in the research survey. The respondents, including industries, comprised of
defence, transportation, electronics and computers, furniture, as well as providers for product
design and industrial design services.

On top of that, for the purpose of this research, three (3) categories of primary
investigations were conducted. Each category of investigation was conducted to identify the
following:

- **Category 1** – The perception of industries towards industrial design in the product
development process.

- **Category 2** – The importance of industrial design in modular product development.

- **Category 3** – The actual application of industrial design in each stage of the generic
modular product design process.

The details and the findings of each of the category are comprehensively described in
*Chapter 4, Section 4.3.*

The following task in the investigation had been analysing and recording the results of
the surveys. The findings were assessed through self-assessment, as well as external
assessment approaches. Self-assessments were carried out by referring to and comparing
literatures of related investigations outcomes mainly from journals articles and conference
papers of related subjects. Besides, analysing and comparing the findings of the data
available in existing literature with the actual survey results should enable the conclusion of
crucial new information that had been needed to progress the research. External assessments
were also conducted on the findings from the surveys in order to ensure that the new data
were accurate and significant from the external assessor’s point of view, in order to achieve
the intended objectives of the survey. This was done through cross-assessment of the results
with several selected respondents involved in the survey. During the cross-assessment
exercise, the results of the questionnaire filled by a respective respondent were disclosed and
discussed openly with the respondent. The discussions posed as an important platform to
ascertain the key role of the respondent in relation to applying industrial design in their
business. The cross-assessment exercise also enabled the results to be validated and
acknowledged by the respondents.
The assessed results were recorded as validated information, which provided more evidence of the actual industrial design activities practiced by the respondents. This information also provided more perspectives on the actual implementation of industrial design within the modular product development process.
Chapter 3

3. Product Design and Development Process Literature

Objectives: This chapter reviews the literature in the domain related to product innovation and design within the product research, design, and development industry, with primary interest in:

- Product design and development innovation.
- Design, design tasks, and processes structure.
- Product development, with emphasis on design creativity and innovation through Industrial Design.
- A broader look at existing examples of Industrial Design and modularity related work.

3.1 Product Innovation

“Innovation – It's something everyone is in favour of, everyone likes the idea of, yet no one really understands it” (Kevin Werbach)

Innovation is often associated with change, new products or ‘novelty products’. In the broadest context, ‘to innovate’ is ‘to begin or introduce (something new) for the first time’, and ‘innovation’ has the meaning of ‘the act of introducing something new’ – The American Heritage Dictionary (2000). Innovation needs to be carefully nurtured and developed within the business environment and an innovative design culture is mostly associated with the company personnel’s attitude towards being innovative (Anthony et. al., 2008; Campbell and Collins, 2001; Chayutsahakij and Poggenpohl, 2002; Kimbell, 2002).

The process of product innovation starts with inputting creative ideas, which are then transformed to create outputs in the form of new products. This process is rather complicated and companies’ trying to develop their innovative capabilities must place a new emphasis on design and development activities, which must also be prudently organized and managed. Moreover, the product companies must place emphasis on establishing strategic innovation
plans if they are to achieve the level of product innovativeness that suits their business direction.

With regard to the strategic innovation plan, there are four (4) basic categories of innovation strategy (White and Bruton, 2010; Baxter, 1995). Please refer to Table 3.1 for the summary of the strategies.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pioneering</td>
<td>Aims to provide technical and market leadership. This strategy depends heavily upon R&amp;D to introduce both radical and incremental innovation to the market ahead of the competitors. This is a proactive strategy and has a long term perspective on return of investment.</td>
</tr>
<tr>
<td>2. Responsive</td>
<td>Aims to respond to pioneering competitors. This strategy intentionally lets other companies to undertake new product development and opens up new markets. Besides, it often strives to improve upon pioneering product.</td>
</tr>
<tr>
<td>3. Traditional</td>
<td>Adopted by product companies operating in a stagnant market with a largely mature range of products, where there is little or no market demand for product change. Innovation comes in the form of minor changes in order to reduce costs, ease production or increase product reliability. Poorly equipped to innovate when forced to do so by competition pressure.</td>
</tr>
<tr>
<td>4. Dependent</td>
<td>Depends upon their parent company or their customers for innovation. In-house innovation is usually limited to process innovation.</td>
</tr>
</tbody>
</table>

*Table 3.1 – The four basic types of product innovation strategy*

### 3.2 Product Development

Product development is a set of activities that begins with the perception of a market opportunity and continues through a structured and systemic process of production, sale, and distribution of a product (Ulrich and Eppinger, 2004). For a company to be competitive, it is very important that its product development strategy is successful in order to determine the long-term viability of the company in the market. An important part of product development is the engineering design process (Ertas, 2012). This process is defined as defining and developing a system, component, or process to meet the desired user needs.
3.2.1 The Product Development Process

New product development can only start after a risk assessment exercise has been conducted. Although the product development risk cannot be entirely eliminated, minimizing the risk and uncertainty is the essence of effective product development. In developing a new product, a well-defined and systematic process is needed to control the costs and time taken to achieve the tasks. The product development methodology is required to convert user needs into a technical and commercial solution, while the role of product development is to fulfil the complete consumer experience, whereby the basic aim of product development process is to transform the needs of consumers into sellable product (Whitney, 1990).

Product design and development is a highly complex and unique process as there is no single process model that is exactly suitable for any managerial decision making. However, a generic product development process that has already been well-defined and a benchmark for methodology is the ideal ISO 9001 Design and Development Process (Refer to Section 3.2.2). Generally, the design and development process is a sequence (Refer to Figure 3.1) of all the required activities and events that any company need to perform in developing, manufacturing, and selling their product. Any real design and development process is actually quite complex and the details of the activities, as well as the events, vary for different product categories.

![Figure 3.1 - General sequence of activities in generic product development process (Adopted from Kamrani, 2000; Ulrich and Eppinger, 2000)](image)

There are two product development methods, which are commonly applied in the industry – Sequential product development, and Simultaneous (or integrated) product development (Craig and Stark, 1994). These methods broadly consist of several groups of activities that involve identifying the demand or opportunity for a new product, conceptualising and developing technical specification for the new product, developing the
production process, and producing the new product. Out of the two methods, there are various product development processes available to be adapted by product organisations. However, the choice of which process is suitable greatly depends on the classification of industry the product organisation belongs to. The following depicts the three (3) main product development processes that are familiar with most organisations:

1. **Total Design** – The concept of ‘Total Design’ process was introduced by Stuart Pugh. Total Design is defined as the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need (Pugh, 1991). Total Design aims to achieve efficient and effective product development by allowing the integration of technological and non-technological components within the development process phases. The product development process activities have a central core that comprise of six (6) development stages – market investigation, establishing product specification, product concept design, product detail design, product manufacturing, and selling of product (Refer to Figure 3.2). Total Design is categorised as a sequential product development method.

2. **Stage Gate Process** – A Stage-Gate process is a conceptual and operational road map to develop a new product project from ideation to launch (Cooper, 2011). This process divides the effort into stages, which are separated by management decision gates. Management approval must be obtained by the project cross-functional teams in each stage in order for them to proceed to the next level of product development. Product development begins with an ideation and completed with a successful launch of a new product. There are five (5) key stages – Scoping, Build Business Case, Development, Testing and Validation, and Launch. Stage Gate Process is categorized as a sequential product development method.

3. **Concurrent Engineering** – This process is also known as simultaneous engineering. This process is defined as the practice of considering the entire product life cycle, from design to disposal, in an integrated design process. The application of concurrent engineering requires the process of designing and developing products to be executed simultaneously or concurrently in each stage, rather than consecutively. The advantages of this process is decreased product
development time and also the time to market, leading to improved productivity and largely cost efficient (Kusiak, 1993). Concurrent Engineering process is categorised as a simultaneous product development method.

Apart from that, many industry leaders see new product development as an ongoing process – often referred to as continuous development in which the entire organisation is always looking for opportunities to develop and introduce new products into the market.

Figure 3.2 – A visible operational structure of ‘Total Design’, which is separated into six iterative stages of the design process. The structure enables uninterrupted flow of information between stages, while enabling the formation of multi-discipline project teams (Source: Pugh, 1991).
3.2.2 Ideal ISO 9001 Design and Development Process

The ISO 9001 Design and development process (Refer to Table 3.2) should be considered ideal since it is based directly on ISO 9001 (Schoonmaker, S.J., 1997; American Society of Quality Control, 1994). Figure 3.3 shows an overall view of the proposed ideal process. This most basic view can and should be compared to the ISO 9001 standard paragraph 4.4 on Design Control. This particular paragraph within the ISO standard is the most crucial area of the standard for the design, as well as engineering section of an organisation.

![Figure 3.3 – The ideal ISO 9001 Design and Development Process (Adopted from: American Society of Quality Control, 1994)](image)

The configuration of the design and the development stages shown above are, however, an approximation of the ideal process as any real design and development process is more complex than the one shown. The idealised process assumes that the customer requirements flow directly into the design department where the design is to be created to meet those requirements. In this case, the integration of other processes, such as industrial design, may be applied throughout the entire process or in specific stages within the process. The integration of industrial design into the ideal ISO 9001 process activities will certainly add complexity to the process, thus requiring an integration tool that is prudently structured. While industrial design encourages creativity throughout its processes, these approaches should be mediated to ISO 9001 in order to ensure that the product released meets the international design standard. Working industrial design within ISO 9001 would eliminate or minimise the amount of product deficiency by meeting the customer’s requirement on initial interaction with the product.
1. **Design Input**

The task of the design input stage is to prepare the customer’s requirements for the design from the internal perspective of the organization. The design input stage is to refine the customer requirements into a design specification and create the documentation needed for the later stages. The design input stage must be given as much attention as possible. The personnel involved in this stage must also be proactive.

2. **Design Output**

The design output stage is where the design and engineering section of an organization prepares the document package for a product’s design. Several demands are set, which include checking that the design output meets the design input requirements, containing and referencing acceptance criteria, and identifying safety related issues in all aspects of the product’s life cycle.

3. **Design Validation**

This is an assessment stage where a decision needs to be made concerning the new product (new design), whereby the organization decides if their product does in fact meet the customer’s requirements. Generally, an activity for management and marketing personnel in the context of the customer’s original request for a new product, the main purpose of design validation is to answer the question of whether the design is going to satisfy the customer.

4. **Design Verification**

Design verification is generally a technical activity for designers and engineers to ensure that the output from the design stage meets the requirements of the design stage input. This activity is done within the organization’s boundary and must also include a meeting described as design authentication.

5. **Design Review**

This is a stage where the design of a product is critiqued by participants from appropriate departments. This session is documented and the documentation is expected to be controlled and made available to auditors. The design review activity should be incorporated into the design output stage and must be conducted before the design validation stage.

| Table 3.2 – The ideal ISO 9001 activities elaborated (Source: Schoonmaker, S.J., 1997) |

3.2.3 **Product Development Category**

A company may apply any of the two product development methods – *Sequential* or *Simultaneous*; however, several considerations need to be made on the appropriateness of the choice of method. This is where product development categories need to be put into consideration. Generally, there are six (6) categories of product development (Kamrani and Salhieh, 2000). The categories are:

1. **Market-pull product development** – which uses markets and customers to perform as the cause that initiates the development of a new product. The markets and customers provide the requirements that the product must meet.
2. **Technology-push product development** – requires companies to start with a pre-established technology and try to find a market opportunity where this technology can be appropriately applied.

3. **Process-based products** – the production process of this product is considered as the main constraint that influences the design of the product and it is usually done for mass production or continuous production.

4. **Platform product** – built around a pre-existing technological system (platform), which is normally very expensive to develop. Any company that adopts this category must incorporate the system into as many different products as possible in order to justify the large capital investment in developing it.

5. **Customized products** – developed in direct response to customer requirements and are usually variations of an existing standard configuration of the products type.

6. **Modular product** – designed as building blocks that can be grouped together to create a variety of different products.

Product development is almost always determined by market opportunity and users’ requirement or demand, and rarely a product is developed to seek demand from the users.

**3.2.4 Product Development Organisations**

The new product development process typically requires a development team that comprises of cross-functional members of design, engineering, and marketing expertise. The cross-functional team must be organised effectively, where individual designers, engineers, and marketing experts are linked together into a group (Ulrich, Eppinger and Steven, 2004). The links among the individual in the team may be formal or informal. In fact, several types of links have been identified (Ulrich and Eppinger, 2000), including:
• **Reporting relationships** – a classic notion of supervisor and subordinate, and they are the formal links that are most frequently applied.

• **Financial arrangements** – part of the same financial entity, such as that defined by a particular budget category or profit-and-loss statement.

• **Physical layout** – often informal and develop from spontaneous encounter while at work.

In the industries where products are technically very complex, the research and development process is typically expensive. A complex product with a relatively short life cycle makes it un-economical for an organisation to develop on its own, and therefore, a strategic link or collaboration among several organizations is needed to help spread the costs. The collaboration also provides access to a wider skill set, and speeds the overall process of the development.

Regardless of the types of link applied, the team is responsible for all aspects of a project from initial idea generation to final commercialisation of the product. The team normally reports to senior management, who is often a vice president or a program manager (Ullman and David, 2009). The strongest organizational links are those with projects involving performance evaluation, budget, and other resource allocation.

### 3.3 Product Design

*“Product design is much more than a blind search for a successful creation. It is founded on principle we must learn and repeat.”* (Unknown author)

Product design is a *set of technical activities within a product development process* that works to meet the marketing and business case vision. This set of activities includes refinement of the product vision into technical specifications, new concept development, and embodiment engineering of a new product. At its most basic level, product design has two (2) important aspects: 1). *An idea emanating to satisfy some needs*, and 2). *A physical embodiment of the idea of a product* (Otto and Wood, 2001). The former entails the process.
of design, whereas the latter is a component of manufacturing. Depending on the choice of development method, product design process is done either sequentially or simultaneously.

The product design tasks may be classified as original design, adaptive design, and variant design (Otto and Wood, 2001). Original design involves elaborating original solutions for a given task, which is called an invention. Original inventions are often high risk opportunities for challenging a marketplace and eventually dominating it. As for adaptive design, it involves adapting a known system to a changed task or evolving a significant subsystem of a current product. This type of design dominates the vast majority of the design activities. Meanwhile, variant design involves varying the parameters of certain aspects of a product to develop a new and more robust design. This type of design usually focuses on modifying the performance of a subsystem without changing its configuration.

Another way of classifying a design task is to consider the discipline within which the process operates (Otto and Wood, 2001), which includes mechanical engineering design, electrical engineering design, architectural design, industrial design, automotive design, furniture design, aerospace design, etc. Each design has its own design process used in its development.

3.3.1 Characteristics of Successful Product Design

A successful product design is seen through different perspectives (Pugh and Hollins, 1990). A profit oriented organisation would consider its product a success when the product design meets the design objectives and satisfies the users’ needs, which consequently create high market demand to generate sales profit. From the perspective of the design and development organisation, a successful product design could be achieved through good product planning exercise.

Nevertheless, good product planning, apparently, is difficult to achieve as it is also costly and time consuming. Furthermore, the efforts put in developing new technology for the product could not guarantee the success of the product if the technology is not complementary with the strong appeal that creates users’ desire to own the product. This shortcoming could also be the consequence of ‘partial design’, whereby engineers and designers focus on their own specialty within the design activity (Pugh et al., 1996) when
collaboration within the cross-functional team should be emphasised. Due to lack of consideration about the market, users’ needs, and the resources of the organisation; the product design process is done on an ad-hoc basis, which will often lead to commercial failure of the finished product. Inevitably, good product planning can ensure the success of a product in the market regardless of the design and development process employed. However, the process must be supported by a precise process definition that the design team can refer to.

### 3.3.2 Creative and Innovative Product

![Dyson Ball range of Dyson vacuum cleaner](image)

**Figure 3.4** - Dyson Ball range of Dyson vacuum cleaner – The innovative roller ball concept makes the product more manoeuvrable and steers smoothly with a turn of the users’ wrist. The centrifugal suction technology innovation also gives the product added advantages as it does not require any dust bags, and therefore, it has no loss of suction (Dyson Limited, 2008).

A creative product is usually measured by the most exciting and challenging design that is considered innovative, and loosely defined as the creation of a radical move from the conservative design currently in the market (Baxter et al., 2009). However, most of the products in the market today rely heavily on the market needs and the drive to top the competitors list; therefore, creativity in products is generally influenced by competition that is purely on the basis of price, which in turn determines the overall features and performance of the product. Many of the products, especially consumer products in the market today, are
mature in terms of concept and application. The design of the products is also very much similar. In order to have the competitive edge, many product companies turn to product styling to differentiate their product from their competitors. The styling differences of the product can have a significant impact and perception of the customers. The creativity and the innovation aspects of the design also need to be visually and technologically distinctive for a product to have significant advantages in the consumer product market, as demonstrated by a Dyson’s household product range (Refer to Figure 3.4). This approach requires product companies to be creative and innovative at every phase of the product development process right from identifying opportunities, designing, and engineering of the product.

3.3.3 Product Styling

Styling is an important way to add value to a product without changing its technical performance or the sophisticated technology used in its system. The styling of a product can transform the product into an artefact of beauty, which is admired for its appearance rather than its function. However, product styling is a very complicated process with a lot of complex significant factors to consider. Product styling is a process that should be continuous throughout the design and development process and must not be considered as an additional or contingency process that is applied at a single point of time (Baxter, 1995). Besides, in his survey on product styling in manufacturing companies that employ design consultancies has revealed that these companies usually applied product styling at the end of their design and development process. Moreover, it was found that most of the companies did not apply the styling process until they had completed the technical and the functional aspects of the product design. The styling of a finished product had been discovered to be difficult as at this stage, it is constrained by other technical factors that would have dominated the overall design of the product. Therefore, product styling must be integrated into the overall product design and development process and the styling decisions need to be made at every phase of the process. Product styling of a product is also very much influenced by industrial design. The utility and the aesthetics needs, which form the core objectives of the industrial design, play a crucial role in determining the styling direction of a product.
3.3.4 Product Industrial Design

Product industrial design initially started in the early 1900s (Lorenz, 1986) when several German industrialists engaged craftsmen and architects to design products for them to manufacture. These industrialists also promoted the development of prototypes for their products. The products designed by these craftsmen and architects did not follow the traditional design approach that were influenced by classical architectures, rather they were different in many ways. These products were designed to emphasize the importance of geometry, precision, simplicity, and economics. The new approach resulted in a new design theory to be known today as industrial design.

![American Car](image)

**Figure 3.5** - American car, such as the Cadillac 1959, features streamline bodies with tailfins and heavy chrome front.

In the early days of product industrial design, industrial designers mainly concentrated in the field of automobile, electrical products, and furniture. These products were useful to the public; however, they lacked the aspect of creativity needed to enhance the appearance of the products. Other than that, the Bauhaus movement (Siebenbrodt and Schobe, 2012) is one of the most prominent European theories on industrial design that promoted product design beyond functionalism. The product appearances were enhanced through the introduction of symmetrical geometries and simplicities. However, there are distinctive differences between the concepts of the European and the American approaches to industrial design. Instead of emphasising on geometries and simplicities, the American approach to industrial design emphasised on streamlining (Refer to Figure 3.5) where the products were designed with
non-functional aerodynamic shapes with the intention to create product appeal. This approach was a success as streamlining was extensively used in designing products, such as automobiles, electrical appliances, and furniture. The streamlining approach was a significant success in America, which led to increased demand in consumer products.

Nonetheless, the concepts of early product industrial design gradually changed with increased competition of similar products in the marketplace. In the early days of product design and development process, there was little emphasis on user product interactions and utilities, as the main concerns of product designers and developers were concentrated on the product mechanical reliability (Gruner & Homburg, 2000) and external aesthetic appeal. This situation has forced companies to search for new ways to compete, and therefore, instead of relying only on aesthetics appeal, product companies also need to improve on other features, such as user product interactions and product utilities. These features had become increasingly significant and vital for the success of a product. At present, product companies have come to acknowledge the role of industrial design as more than just concerning the appearance and the shape of a product. Industrial designers are also capable in determining how the product interacts with users, and its effects in terms of ease of use. Today, modern product industrial design is derived from complex amount of processes, which involve extensive research and definition into user needs, product architecture, utility and ergonomics, styling and aesthetics, as well as corporate strategies.

3.3.4.1 Industrial Design Process

![Figure 3.6 – Generic industrial design process (Adopted from: Ulrich & Eppinger, 2000)](image)
The process of industrial design has been described as phases of activities that are primarily user-driven rather than technology driven (Gemser et al., 2006; Walsh, 1996). This implies that the industrial design process relates mainly to aspects between the user and the product rather than the relations internal to the product. Therefore, activities that relate to the technical aspects of the product do not fall under industrial design. Instead, these activities are generally engineering related.

As described earlier in this chapter, modern industrial design is derived from a complex number of processes, which involve extensive research and definition into the product architecture, user needs, styling, and corporate strategies. The process of industrial design, however, cannot be performed alone as it must be integrated into the total design and development process (Refer Chapter 4, Figure 4.11) in order for the process to create the intended outcome of a product. The generic process of industrial design (Refer to Figure 3.6) includes an investigation of customer needs, conceptualization and design, preliminary refinement, final concept selection, I.D. product drawing, and co-ordination with other sections during product release (Ulrich and Eppinger, 1995, 2000). For each stage of the process, emphasis is given to achieve the final goals of satisfying both the manufacturer and the consumer needs by continuously considering the industrial design critical measures (Abdullah, 2011) (Refer to Table 3.3).

<table>
<thead>
<tr>
<th>Industrial Design Critical Measures</th>
<th>Outcome Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Usability (Utilities)</td>
<td>Ease of use; ease of maintenance; quality and quantity of interaction; safety; novelty of interaction; ergonomics</td>
</tr>
<tr>
<td>2. Aesthetics</td>
<td>Product differentiation; pride of ownership, image and fashion; communication.</td>
</tr>
<tr>
<td>3. Costs</td>
<td>Cost benefits and trade-offs; appropriate usage of resources.</td>
</tr>
<tr>
<td>4. Production</td>
<td>Manufacture and assembly; appropriate usage of raw materials; tooling; packaging.</td>
</tr>
<tr>
<td>5. Product life-cycle</td>
<td>Life-cycle design; material selection</td>
</tr>
</tbody>
</table>

Table 3.3 – Industrial design critical outcomes and objectives

The industrial design process is one of the key elements that form the generator mechanism of the InDFM. This is aligned with the analysis and the reviews on industrial design contributions towards product performance (Candi and Gemser, 2010), as industrial
design could be an important strategic tool in developing modular products. This statement is supported by Sanchez and Collins (2001) by outlining the potential strategic importance of industrial design (Refer Table 3.4).

<table>
<thead>
<tr>
<th>Strategic Importance</th>
<th>Strategic tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design concepts</td>
<td>Developing design concepts for more extensive product lines in order to increase product variety.</td>
</tr>
<tr>
<td>2. Product design refreshment</td>
<td>Refreshing product designs through styling changes in visible components for technologically mature modular products.</td>
</tr>
<tr>
<td>3. Styling variation</td>
<td>An essential role in modular product strategies by creating styling variations that can effectively distinguish individual product models within a modular product family.</td>
</tr>
<tr>
<td>4. Technology upgrade</td>
<td>Helping to bring a series of technologically upgraded products to market in rapid succession</td>
</tr>
<tr>
<td>5. Performance variation</td>
<td>Providing effective differentiation of new product models by stylising in order to communicate visually the improved technical performance of the new product.</td>
</tr>
</tbody>
</table>

Table 3.4 – Strategic importance of industrial design (Source: Sanchez and Collin, 2001)

3.3.4.2 Innovation through Industrial Design

Modern industrial design does not only concern the visual attractiveness and product functionality, but it is also to solve the problem of innovation, and the need to exploit the hidden value within a brand. The most common notion of industrial design is meeting the needs of consumers; hence the value of industrial design innovation should meet the criterion of consumer demand as its top priority. Industrial design innovation, therefore, must be based on all the characteristics of both the psychological and the practical needs of the consumer. Besides, several researchers have emphasised that industrial designers are more sensitive towards those needs and this has created a new type of innovation described as ‘design-driven innovation’, which has radically changed the emotional and the symbolic contents of a product (Best, 2006; Verganti, 2008; Dell’Era & Verganti, 2009).

The rise in interest for industrial design by product companies has changed the approach to product development. Nonetheless, in most existing researches, the concept of innovation is limited to new technology and innovation of non-technological nature, which tends to be excluded as it is not considerably innovative. Technology innovation is no longer the dominant contributor for product success. Product companies with minimal technological
innovativeness may perform better through innovative industrial design (Verganti, 2008). An example can be seen from the mobile communication device market in Malaysia as several mobile phone companies developing new mobile phones have increasingly recognised industrial design within their product development phase, and have benefited from it. The technology used in these communication devices developments is practically similar for most products as it can be easily outsourced, but the key to capturing the market is the profound understanding of the local culture and meeting the psychological need of the consumer. These factors act as the determinant differentiator that enables the local manufacturers to compete with the large and established mobile device companies, such as Blackberry, Nokia, Samsung, Apple, and other multinational giants. The industrial design innovation through enhancement of users experience has greatly increased the competitiveness of the Malaysian mobile communication devices by infusing local cultures as value added features (Refer to Figure 3.7).

![Figure 3.7](Image source: Spice CSL International, 2013)

Figure 3.7 – Malaysian made CSL mobile phone introduced the latest Android application Spice series model with essential Islamic features that appeal to most Muslim users in Malaysia, such as the ‘azan’ and the direction of the Ka’bah (Image source: Spice CSL International, 2013)

Such consideration and understanding of the local culture, as well as meeting the psychological need of the customers, were also the important keys employed in planning and building the Hong Kong Disneyland theme park in 2003 (Disneyland Report, 2012). The theme park comprised of an entire system of integrated components, such as rides, amusement centres, shopping and food outlets, theatres, hotels, and many more. Hong Kong
Disneyland and CLS mobile phone are two products that obviously belong to two different product categories, however, one factor that connects them together is both product developers applied a similar design concept, which is incorporating local culture into the product design in order to meet the customers’ psychological needs with interesting features close to their culture and traditions (Refer to Figure 3.8). The application of this design concept on both products has proven to give them significant advantages over their competitors.

![Figure 3.8](image_url) – Disney’s cartoon characters wearing traditional Chinese attire demonstrated the integration of local culture into Disney’s product, albeit randomly, has successfully captured the hearts of Chinese customers to visit the Hong Kong Disneyland (Image: © The New York Times, 2009)

### 3.3.5 Industrial Design in Product Development Process

There is a close relationship between industrial design and the needs of users. This is evident as the levels of users’ satisfaction vary; hence the needs have become the driving force in industrial design (Lu L., and Wang Y., 2011). Furthermore, there are also evidences that support the belief that industrial design has a valuable role to play in new product development. According to Desbarat (2000), effective industrial design and new product development are the links that build real brand value. The role of industrial design in product development process is to fulfil the complete consumer experience that may start with how a product looks and leads to how a product feels, sounds, and makes one think (Sawhney, 2007).
As previously mentioned, the discipline of industrial design emerged during the early 20th century to provide services for manufacturing industry. At present, industrial design is one of the important aspects of product development process (Refer to Figure 3.9), and has been often regarded as a key aspect of a company’s success in the market place. Moreover, the wide range of knowledge and expertise of the industrial designers enables them to make significant contributions within the contemporary and globalised system of product development and manufacturing (Walker, 2002). Industrial design defines an approach that represents a particular set of knowledge and skills in which it is a vital part of the product development process. However, despite of this success, industrial designers still face resistance when offering their services and arguing their perspectives, whereas during economic downturn, industrial design spending is frequently the target of cut back as it is deemed as not essential for survival (Candi and Gemser, 2010).

### 3.3.6 Industrial Design Measures

As mentioned by Candi (2010), the terminology of industrial design defers in perspective and application, and therefore, the terms of the kind of measures used for industrial design are also varied. Generally, there are four (4) categories of industrial design operationalisations or measures (Candi and Gemser, 2010). The measures include industrial
design emphasis, capabilities, outcomes, and management. These measures form one of the vital aspects in determining the mechanism of the InDFM. Having both the industrial design and modular design process integrated based on the ideal ISO 9001 design and development process standard, the industrial design creative inputs adhered to the principles of modular design; as these measures are important considerations to mark out the application potential within the design and development process. The next sections further describe each individual measure.

3.3.6.1 Emphasis

Industrial design emphasis is connected with an organisation’s or company’s strategy to include or exclude industrial design in their product design activities and also the degree to which industrial design is included. Some of the major measures of industrial design emphasis on modular product design include the influence of industrial design at the senior decision-making level of an organization, the degree of industrial design involvement in the different phases of modular product design, and the management assessments of the weight placed on industrial design in the modular product design process. Besides, the objective measure of industrial design emphasis includes the number of specific industrial design activities performed during a modular product development project.

3.3.6.2 Capability

To examine the relationship between industrial design and performance (Candi and Gemser, 2010), a common approach is to focus on the industrial design capabilities available and exploited when designing and developing a new product. The number of in-house Industrial Designer or external design consultants (Gemser and Leenders, 2001) used in modular product design projects is one of the important aspects related to capabilities measure. Other capability measures include the hours spent on industrial design in a modular product design project, as well as assessing and comparing industrial design budgets to total modular product design and development expenditures.
3.3.6.3 Outcome

On the other hand, industrial design outcomes are defined as the exhibited industrial design characteristics of a product (modular). Contrary to industrial design emphasis and capabilities, which are variables describing the amount of something, industrial design outcomes are the measure of “goodness” of a product, which is generally associated to areas of usability and utility, aesthetics, cost, manufacturability, and product life-cycle. To assess industrial design outcomes, customer evaluations and evaluations by industrial design experts are used.

Besides, the industrial design outcomes form the most vital component of the InDFM as its attributes, in particularly aesthetics and usability aspects, have a profound impact on user perception of successful industrial design. Thus, it is a common practice for users to evaluate the effectiveness or the success of the industrial design on a product through its aesthetics and usability recognition. However, since industrial design is not just about these two attributes; it is equally important to evaluate other attributes to measure industrial design outcomes.

3.3.6.4 Management

Industrial design management capabilities are structures and practices set up to deploy industrial design and to maximise industrial design outcomes. Effective industrial design management is needed to achieve effective industrial design investment (Chiva and Alegre, 2009). In general, three (3) issues are related to industrial design management. The first issue is to define the method of administering industrial designers whether to utilise external or internal, or a mixture of both in the modular product development process (Vanchan, 2007). The advantages and the disadvantages of employing these methods are observed. The second issue is to identify the extent to which industrial designers should be integrated into the modular product design and development process. There are different opinions and views on the integration of industrial design into the product design and development process, whether to integrate it later in the process or throughout the process, and there can be conflicts of perspective among the Industrial Designer and other cross-functional team members (Maciver and O'Driscoll, 2010; Perks et al., 2005; Brown, 2008; Veryzer and Borja de Mozato, 2005; Gemser et al., 2006). The final issue related to industrial design management
is whether product organisations should try to create innovative designs or adopt an evolutionary design approach. Reviews have shown that product organisations are more successful in terms of market acceptance through innovative industrial design rather than innovative technology (Dell’Era and Verganti, 2007). Moreover, a number of good examples can be observed from the Asian perspective, such as Samsung and LG (South Korea), and Hitachi (Japan). During the recent 1997 – 2000 economic downturn in Asia, these companies depended extensively on industrial design innovativeness, particularly in the aspect of aesthetics and fashion. The application of industrial design as cost effective alternative to technology innovation had earned these companies significant revenue to endure the economic crisis (Lingxia and Yanxun, 2010). Many of these companies’ product design top management are industrial design literate. Innovative industrial design requires in-depth understanding of the changes in society, culture, and technology (Veganti, 2008); thus the strong management and understanding of industrial design innovativeness of the top management is vital during the development process.

3.4 Defining Product Architecture

All products are created and designed based on architecture. This applies to any product ranging from software, hardware, services, and other categories of manufactured goods. Once a design concept has been established, embodiment design follows by exploring the arrangement of the elements of a product as the initial stage of dividing the product into components. The arrangement of the elements can be thought of in both functional and physical terms. Product architecture is the assignment of the functional elements of a product to the physical building blocks of the product. The architecture of a product design (Sanchez, 2002) refers to:

- The way the overall functionality of a product design is decomposed into functional components.
- The way the functional components are intended to interact in the product.

Other definitions of product architecture (Ulrich, 1995) refer to:

- The arrangement of functional elements.
- The mapping from functional elements to physical components.
• The specification of the interfaces among interacting physical components.

The functional elements of a product are the individual operations and transformations that contribute to the overall performance of the product (Ulrich and Eppinger, 2004).

In fact, there are two (2) types of product architecture (Ulrich and Eppinger, 2000):

• **Integral architecture** – An integral architecture includes a complex mapping from functional elements to physical components and coupled with interfaces between components. A product embodying an integral architecture is designed with the highest possible performance in mind. The best example of product with integral architecture is a modern race car (Refer to Figure 3.10). A modern Formula 1 racing car allows specific algorithm adjustment for different circuits (Piancastelli et.al., 2012) in order to give the best output results from each run, and therefore, the structure and the component design must be constructed to meet the required algorithm.

![Figure 3.10 – A Formula 1 racing car design embodies an integral architecture for optimisation of performance on different circuit layouts (F1grandprix.net, 2014)](image)

• **Modular architecture** – A modular architecture has a one-to-one correspondence between modules and functions. It is built of sub-systems or modules that interact with each other, and allows design change to be made to a module without changes to other modules for the product to function properly. One of the products that have greatly benefited by adopting modular architecture is the personal computer system (Baldwin and Clark, 2000). Modular architecture has changed the computer industry ‘physically and mentally’ by modularising the physical and the software components of the
computer (Refer to Figure 3.11). This development has also given rise to the advent of new sub-industries in the computer industry (Holland, 1992).

![Computer Image](image)

**Figure 3.11** – Embodiment of modular architecture for the desktop computer enables configuration of unlimited number of product variation through configuration of physical components and software (Hp Computers, 2010).

3.4.1 Implication of the Architecture

The architecture of a product is closely linked to decisions about marketing strategy, manufacturing capabilities, and product development management (Ulrich and Eppinger, 2000). These decisions are influenced by several issues of importance to an organization. Those issues include:

- **Product change** – Product architecture defines how a product can be changed. The motives of the change include product upgrade, components add-on, component adaptation, component deterioration, material consumption, flexibility in use, and reuse of the main component.

- **Product variety** – Products of modular architectures are flexible and easily varied without complex redesign and modification to the components. Manufacturing and assembling of the components can also be done without complex changes to the manufacturing and assembly system.
• **Component standardization** – The component standardization allows the product organization to manufacture similar components that can be used in multiple products. The components may be manufactured in large volume, which in turn, lead to lower production costs.

• **Product performance** – This is defined as how well a product implements its intended function. Products with different architecture designs produce different performance levels. The performance of a product on integral architecture is always better in comparison to the performance of a product on modular architecture. This is because; integral architecture facilitates the optimization of performance, whereas modular architecture emphasises on components standardization and variations of products.

• **Manufacturability** – Component integration is one of the important manufacturing strategies and this can be achieved through the choice of product architecture used. The manufacturing processes and costs can be minimized through component integration with reduced number of components used.

• **Product development management** – Integral and modular product architectures demand different project management styles. Products on integral architecture require less planning and specification during the system-level design, whereas products on modular architecture need thorough and precise planning during the system-level design.

  Moreover, product architecture decisions with broad implications and inputs from the marketing, manufacturing, and design teams are essential in this aspect of the product design and development for the organization to make appropriate decision on the mentioned issues.

**3.4.2 Establishing the Product Architecture**

Product architecture should be established in a cross-functional effort by the product development team. This is essential as product architecture has a considerable impact on the subsequent product development activities. This also influences the manufacturing and the marketing of the completed product. Besides, Ulrich and Eppinger (2000) recommended a four-step method to structure the decision process. The four-step method includes:
1. Creating a schematic of the product.
2. Clustering the elements of the schematic.
3. Creating a rough geometric layout.
4. Identifying the fundamental and incidental interactions.

The method will lead the development team through the preliminary decision on which architecture to use. Subsequent processes, such as system-level and detail design activities, will contribute to the ongoing development of the architectural details.

3.4.3 Modular Product Architecture

The most important characteristic of a product’s architecture is its modularity (Ulrich and Eppinger, 2000). A modular product’s architecture is an architecture that is designed to allow the ‘mixing and matching’ of different component variations in the overall product design in order to configure product variations. Three types of modular product architectures (Ulrich, 1995) comprise of: 1) Slot-modular architecture, 2) Bus-modular architecture, and 3) Sectional-modular architecture. Each type of architecture embodies a one-to-one mapping from functional elements to the major physical building blocks. The differences between the architectures are the configuration in the way the interactions between the physical building blocks are organised. Refer to Section 3.6 for further description on modularity characteristics and typologies.

The configurability of an overall product design is achieved by specifying component interfaces that allow the substitution of component variations into the product design, without having to change the design of other components in the product architecture both in functional and physical way (Sanchez, 2000). This provides greater improvement in product re-configurability, which increases variety and the speed of introduction of a new product into the competitive market (Refer to Figure 3.12). Maintenance and service of the product is also easier as spares and replacement components are readily available due to subsequent modularisation of these components.
Figure 3.12 - Scania’s modular truck cab. The modularised cab provides greater improvement in product re-configurability, which increases variety and the speed of introduction of a new product into the market (Ericsson and Erixon, 1999)

3.5 Mass Customisation

Economic and political changes have led to de-regulation in many industries and the removal of trade barriers in many others (Kratochvil, 2005). Besides, the global market is becoming saturated, while the customers’ knowledge and discernment is increasing as well. Customers are becoming both cost-conscious and demanding, which have led to increased awareness and greater access to similar products. This infinitely leads to increased competition and price sensitivity. With that, mass production has shifted to another frontier known as mass customisation, where customised products are produced in massive amount to meet customers’ demand, which has been proven to be highly successful for many companies throughout the world (Coletti & Aichner, 2011; Tseng & Jiao, 2001; Pine, 1992). Mass customisation is defined as the making of tailor-made goods or services in a manner that is economically viable. The application of mass customisation is not dedicated to a specific sector. Product organisations that intend to apply mass customisation must be aware that it requires an appropriate adaptation of the existing manufacturing processes to be successful (Probst et al., 2013). Meeting customers’ need through this concept also enables the manufacturer to stimulate market demand (Westbrook & Williamson, 1993).
Mass customisation is cross-industrial and applicable to most business sectors. The automotive industry is one of the best examples where mass customisation approaches are extensively applied (Alford et al., 2000). Automotive manufacturers face fierce competitions especially in the passengers’ car production, whereby the cars have shorter product life cycles and faster delivery of new cars into the market. The manufacturers must customise all aspects of product development, production, marketing and distribution of goods and services with varieties that nearly every user finds exactly what they need at a price that is affordable to them. Today, apart from automotive industry, many sectors have successfully implemented such strategies: food industry, electronics, large engineered products, communication devices, defence equipment, personalised nutrition, homebuilding, and others.

3.5.1 Techniques and Classifications of Mass Customisation

In order to achieve mass customisation, several techniques have been proposed and studied, such as post-postponement in supply chain management (Lee and Billington, 1992), design for variety (Ishii et al., 1998), product line planning and high-variety production planning and control (Morgan et al., 2001), and product family architecture (Du et al., 2001). These techniques are focused on such backend efforts of product realisation as design, manufacturing, and logistics in order to enhance the capabilities for mass customization. Besides, some techniques like modularity, commonality, standardisation, and later point differentiation can enable a wide coverage of customer preferences while reducing manufacturing cost, shortening the production cycle, and enhancing product line flexibility. The issues addressed by these techniques are mostly related to technical variety – the diversity of engineering realisation in order to achieve various specific customers’ needs (Alford et al., 2000).

On top of that, manufacturers can use several methods to achieve mass customisation (Åhlström and Westbrook, 1999). These methods are classified by:

- **The degree of organisational transformation that is required.**

This refers to the initial point in the manufacturing process where customers can alter their products (i.e. point of customer involvement). The degree of organisational transformation required largely depends on the initial point of customer involvement and
it is broken down into four types of mass-customised products: customised additional services, adaptive products, modular products, and tailor made product (Refer to Figure 3.13).

- The mass customisation approaches that are related to the nature of customisation.

These approaches are related to how customer value can be created and they involve the nature of inherent customisation rather than organisational changes needed. There are also four approaches that can be used to customise the product: packaging change (cosmetic approach), product change (transparent approach), both packaging and product (collaborative approach), as well as enabling customers to customize the product during use (adaptive approach).

According to Broekhuizen and Alsem (2002), the earlier customers can alter production, the better their wishes are met. The uniqueness of the offering is correlated to the initial point of customer involvement.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Design</th>
<th>Fabrication</th>
<th>Assembly</th>
<th>Additional Services</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Collaborative, Transparent</td>
<td>Collaborative, Transparent</td>
<td>Collaborative, Transparent</td>
<td>Cosmetic</td>
<td>Adaptive</td>
</tr>
<tr>
<td>Type of Product</td>
<td>Tailor-made products</td>
<td>Tailor-made products</td>
<td>Modular Products</td>
<td>Customised Additional Services</td>
<td>Adaptive Products</td>
</tr>
</tbody>
</table>

Figure 3.13 - Levels and approaches of mass customisation (Adopted from: Broekhuizen, 2002)

3.5.2 The Best Method of Mass Customisation

Product customisation can be achieved through methods that range from ‘one of a kind’ design through adaptation and modification of a standard product to meet a specific customer’s need (Kratochil & Carson, 2005).

In the production of complex products, modular products are considered to be the best method of mass customisation. For scalability and rapid response (putting the Mass into mass
customisation), the best method of customisation is the ‘Lego brick box’ of modular product to be configured quickly on demand. Another benefit of modular products (related to going global) is the power of mass customisation enabling enterprises to sell whole systems rather than a single product (Kratochil & Carson, 2005).

In practice, there are two approaches of customisation (Duray, 2000). One is called variant customisation (also called tailored customisation), which refers to certain customized products developed by modifying an existing product that can meet similar customer wants. Such a master product is called the base product. The concept of the base products conforms to widely accepted practice of developing product platforms (Du et al., 2001). The other approach is called configurable customisation, which is based on modular design, and thus, customised products result from configurations of various functional modules. Usually, a configured product starts with a core platform offering standard features for a group of customers. Moreover, for illustrative simplicity, this core platform is categorized as a base product as well.

### 3.6 Modular Product Design and Development

The process of modular product design and development results in the creation of products with different complexities using similar components. The components used in the products must have features that allow them to be fixed together to form the products. The products created from these components are categorised as modular products. In order to design and develop a modular product, one has to follow a set of rules (Baldwin and Clark, 2000). A complete set of design rules addresses three categories of design information. The design rules include:

- **Architecture** – what modules will be part of the system and what their roles will be.

- **Interfaces** – comprehensive descriptions on the interaction between different modules, such as how they fit together, connect, communicate, and even blend.

- **Integration protocols and testing standards** – procedures that will allow designers to assemble the system and determine how well it fits and works.
3.6.1 Definition of Modularity

Modularity is a design approach that is familiar to most product designers and developers and it is a powerful design strategy that is used for different functional purposes. The term modularity is defined as having two (2) characteristics: 1) Similarity between the physical and the functional architectures of the design, and 2) Minimisation of the degree of interaction between the physical components (Sanchez, 2002).

The modularity approach is an integral part of mainstream strategic management thinking. This strategy is used in many areas, which cover a broad range of product complexity and modular composition, such as household appliances, computers, automobiles, transportation, plants, etc.

In addition, most product manufacturers use modularity in their production to simplify complex manufacturing processes (Baldwin and Clark, 2000). This approach allows complex products to be made by dividing the manufacturing process into various process modules or ‘cells’. Modularity in use enables customers to mix and match elements to create a final product that satisfies their requirements (Refer to Figure 3.14). The elements are acquired from single or different suppliers and manufacturers, and are fitted together as a single product. This approach is feasible as the elements used are of standard dimensions that constitute the design rules that bind on manufacturers.

In fact, there are several definitions of modularity. For the purpose of this research, the definitions of modularity are listed in the following:

- **Modularity** – This refers to the use of common units to create product variants (Huang and Kusiak, 1998).

- **A modular system** – A modular system is made of independent units that can be easily assembled and behave in a certain way in a whole system (Jose and Tollenaere, 2005).

- **Life-cycle modularity** – Life-cycle modularity entails maintaining independence between components and all life-cycle processes in different modules, encouraging similarity in all components and processes in a module, and maintaining interchangeability between modules (Gershenson et al., 1999).
- **A modular architecture** – A modular architecture has a one-to-one correspondence between modules and functions, which is built up of sub-systems or modules that interact with each other through a set of well-defined rules (Stone, 2000).

![Figure 3.14 - Modular car concept](image)

Figure 3.14 - Modular car concept, which allows mix and match of roof component to create the desired final model (Diamler Chrysler AG, 2007)

All the above definitions imply that the modular products are generally described as products designed as building blocks that can be grouped together to form a variety of products. This strategy is practical to companies in highly competitive environment as modular products are configured quickly on demand.

### 3.6.2 Characteristics and Typologies of Modularity

There are basically three (3) characteristics of modules. These characteristics include:

1. **Hard modules** – These modules have a distinctive physical appearance.
2. **Soft modules** – Soft modules show a limited physical appearance. Examples of these modules are software, financial products, and insurance policies.
3. **Integrated modules** – This type of module is a combination or mixture of hard and soft modules. Some products, such as electrical and electronics devices like televisions and computer screens, consist of a series integrated modules.

<table>
<thead>
<tr>
<th>Modularity typologies</th>
<th>Characteristics description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Manufacturing modularity</td>
<td>Practiced in many industries. This is a technique that produces fully finished product by using pre-manufactured sub-assemblies (the 'modules'), thus facilitates mass customization by producing alternative configuration in a short period of time.</td>
</tr>
<tr>
<td>2. Product use modularity</td>
<td>Implies the use of modules to facilitate product customization by the users. Adaptive customization, as described by Gilmore and Pine (1999), which is nearly similar to this typology although they do not specifically mention the use of modularity.</td>
</tr>
<tr>
<td>3. Limited life modularity</td>
<td>Implies the use of disposable modules with distinct characteristics and must be easily replaceable. In this context, the lifespan of the modules is shorter than the product in which it is used. The modules are designed to be replaced several times over the course of the product life cycle.</td>
</tr>
<tr>
<td>4. Data access modularity</td>
<td>An example of this modularity type is independent data storage devices, which are normally used separately from the system in which they are used. These devices are compatible to most other systems or equipment. Some of these products are CD, DVD, memory card, USB memory stick, etc.</td>
</tr>
</tbody>
</table>

Table 3.5– 4 types of modularity typologies

Moreover, there has been minimal development of modularity typologies for product design and production systems (Sanchez, 1999; Stone, 2000). However, they have concluded that there are four (4) main typologies of modularity (Refer to Table 3.2 and Figure 3.15).

![Figure 3.15 - Module Characteristics and typologies ( Adopted from Arnheiter & Harnen, 2005)](image-url)
Apart from that, Kamrani and Salhieh (2000) described module characteristics as product modularity representation. These representations are based on the types of combinations between the modules. The types of combinations are described in the following:

- **Component-swapping modularity** – Different product variants belonging to the same product family are created by combining two or more alternative types of components with the same basic component or product (Refer to Figure 3.16).

![Figure 3.16 - Component-swapping modularity (Adopted from: Kamrani & Salhieh, 2000)](image)

- **Component-sharing modularity** – Different product variants belonging to different product families are created by combining different modules sharing the same basic component (Refer to Figure 3.17).

![Figure 3.17 - Component-sharing modularity (Adopted from Kamrani & Salhieh, 2000)](image)

- **Fabricate-to-fit modularity** – One or more standard components are used with one or more infinitely variable additional components (Refer to Figure 3.18).
Figure 3.18 - Fabricate-to-fit modularity (Adopted from Kamrani & Salhieh, 2000)

- **Bus modularity** – Occurs when a module can be matched with any number of basic components (Refer to Figure 3.19).

![Bus modularity diagram](image)

Figure 3.19 - Bus modularity (Adopted from Kamrani & Salhieh, 2000)

For most of today’s products, it is very seldom that we encounter a product that applies a single typology. Most of the modular products in the market are generated out of multiple typologies, thus some modules are ‘hidden’ (Baldwin & Clark, 2002). These products are complex products with integration of several different types of modules simultaneously. In general, a correct choice of a module characteristic contributes to the success of the overall product.

3.6.3 The Need for Modularity

The introduction of the modularity concept in product design and development enables product organisation to compete and achieve a number of strategically important
advantages in the product market. The adaptation of the modularity concept in design and development of products has resulted in positive effects for both the organisation and the products itself. The positive effects, however, will depend closely on how the concept is applied (Ericsson, 1999). The appropriate application of the modularity concept should enable the product organisation to achieve four (4) major strategic advantages (Sanchez, 1999 and 2002). The strategic advantages include:

- Greater product variety.
- Faster technological upgrading of products.
- Greater speed in developing new products, and
- Cost reductions.

The other strategic advantages that have been identified are depicted in the following:

- Mass customisation (Duray, 2000)
- Increasing speed to market (Ericsson and Erixon, 1999),
- Decoupling of tasks – concurrent product development (Sako and Murray, 2000),
- Subcontracting/network cooperation (Hsuan, 1999),
- Ease of maintenance, repair, and recycling (Dahmus and Otto, 2001)
- Product family; Economies of scale; Handling of uncertainty; Better integration of marketing and technical objective (Eggen, 2003),
- Handle uncertainty ((Eggen, 2003),
- Better integration of marketing and technical objectives (Eggen, 2003).

3.6.4 Modularity and Cost

Modularisation serves three purposes (Baldwin & Clark, 2002), any of which may justify an investment in modularity. However, one question has not received a definite answer – Does the concept of modularity actually save cost? This is one of the most
fundamental questions that have not been answered appropriately. Modularity creates value, but it is definitely not ‘free of charge’ (Guo and Gershenson, 2006).

Modularisation has been suggested and generally recommended as a product design strategy to facilitate the competing goals of low cost and high levels of variety and flexibility. However, modularisation has been usually described either in generic terms or very product specific. This lack of agreement on definitions has also made it difficult to understand the cost implications of product modularisation. The process of modularisation is extensive particularly for modularising a highly complex product system. Besides, all important design dependencies must be understood and addressed attentively. Each product modularisation has different problems, and the problems increase with the increasing complexity of the design. Thus, the cost of modularisation is also increased accordingly to the level of design complexity. Many researchers have also shown that the detailed design of each module has a great influence on production cost. Therefore, it is important to use appropriate design for manufacturing and assembling principles when designing each of the module (Ericsson and Erixon, 1999).

The cost of architecture, experiments, and test are all inherent in the modular design process itself. The cost of creating a modular architecture with integrated module typologies would obviously be high. This is added to by the fact that it is also expensive to design the tests procedures that are needed to determine if a specific module is compatible with a given system, and which module performs best. Each module in a large system has a unique value profile. Nonetheless, the true benefits of product modularity have remained unproven as there is still no significant systematic method to achieve product modularity (Gershenson et al., 2004). Therefore, there is a need for analysing the relationship between modularity and cost, as a more thorough examination of the modular design procedure is needed (Guo and Gerhenson, 2006). Besides, statistical analysis has shown that the belief of more modular products have lower cost is not necessarily correct (Fixson & Clark, 2002).

3.6.5 Modular Product Design Process

Modularity is an approach familiar to most designer engineers. It is a powerful design strategy, which is now becoming an integral part of the mainstream strategic management thinking (Sanchez, 2002). The term modularity is very simple, however; its definition has
been entwined and somewhat complicated. Perhaps, the simplest definition is ‘Modularity is a particular design structure, in which parameters and tasks are interdependent within units (module) and independent across them (Clark and Baldwin, 2000). From this definition, one can, therefore, define that a modular product design process is the method of creating and developing a product that possesses a modular structure.

![Figure 3.20 – Modular product design process (Adopted from: Kamrani & Salhieh, 2000)]

On top of that, modular product design involves four (4) major stages (Refer also to Figure 3.20). The elaboration of the process overview of each stage is as follows. Typical to any design process, it also begins with a customer needs analysis. Within this stage, the design engineer’s main task is to find out exactly what the needs are and what the customers really want. With this information, the product can be described fully in terms of functional needs and physical limitations. The next stage of the process is product requirement analysis. The results from the first stage are used to identify the product requirements through a list of functional objectives needed to meet the customer’s primary needs. Further analysis of customer needs discloses operational functional requirements and general functional requirements. The third stage of the process is product or concept analysis. This is the decomposition of the product into its basic functional and physical elements, and these elements must be capable of achieving the functions of the product. Product functional decomposition describes the product’s overall functions and identifies component functions, while product physical decomposition decomposes a product into its basic physical components that will accomplish the function of the product when assembled together. The final stage of the process is product or concept integration. In this stage, the basic physical and functional components that result from the decomposition process are arranged in modules and are integrated into a functional system.

In conducting the modular product design process, the design engineer should adhere to the four (4) principles of modular design, as proposed by Doi (1963). Although the
principles were laid out in the context of machine tools design (Ito, 2008), these principles are still very much relevant in guiding the design process of any other modular product today. The principles of modular design are further described in the following section.

3.6.6 Principles of Modular Design

<table>
<thead>
<tr>
<th>Principles</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Separation</td>
<td>Emphasis is put on finding the method of disintegrating modules into a proper number of modules and determining a group of standardized modules according to the design purpose.</td>
</tr>
<tr>
<td>2. Unification</td>
<td>Module should be standardized in full consideration of not only its dimensional specifications, but also its functionality, capability, and structural configuration.</td>
</tr>
<tr>
<td>3. Connection</td>
<td>In employing modular design, the jointing (or connection) method and joint surface should be unified or standardized in the most preferable case while maintaining allowable assembly accuracy.</td>
</tr>
<tr>
<td>4. Adaptation</td>
<td>Various structural configurations with varied functionalities, performances, and dimensional specifications should be arbitrarily produced from a group of modules. The preferable combination and interfacing method among modules is established and evaluated to ensure module compatibility.</td>
</tr>
</tbody>
</table>

Table 3.6 – Principles of modular design (Adopted from: Doi, 1963)

The four (4) principles for modular design – the principles of separation, unification (standardization), connection, and adaptation – are very valuable in rationally applying modular design. The table (Table 3.6) above shows the interpretation of these principles.

The application of industrial design potential into a modular product should adhere to these principles whereby the Industrial Designer should work them to ensure that the industrial design potential does not disrupt these principles, otherwise, the modularity structure of the product would be affected.
3.6.7 Modular Product Overview

The growing number of global product companies is now not only adopting modular product designs, but also adopting new kinds of product strategies and implementing new development processes that are explicitly focused on achieving a range of competitive advantages through modular product design (Sanchez, 1999). Modular products can be supported by conceiving a product ‘platform’, which is essentially the use of standard module between different products (Jose and Tollenaere, 2004). It is also defined as a set of parameters, features, and/or components that remain constant from product to product within a given product family (Simpson et al., 2005). The use of a ‘platform’ has its own implications, such as the use of common manufacturing process, technology, and knowledge, which are shared by multiple products in a family.

Below are examples of modular products, which are just a few of the many examples of modular products that are produced worldwide. Other examples can be found in a list gathered by Sundgren (1999).

- **Personal accessories** – Swatch has developed hundreds of wristwatches varieties based on a few platforms (Katz, 2003). The Swatch platform is a small set of timepiece subsystems linked together through a few electronic interfaces. Société Micromécanique et Horlogerè (SMH) is one of the few wristwatch manufacturers that have managed to cater users from different categories and style (Refer to Figure 3.21).

![Figure 3.21 - Some examples of Swatch wristwatches sharing a similar platform. Almost all the watches use similar platform, which is simple and cheap to manufacture, and capable of supporting extensive external variations (Swatch AG, 2007).](image-url)
• **Power tool product** – Black & Decker purposely invented a power tool platform – an electric motor and controls – on which the company could base extensive consumer power tool; electric drills (Refer to Figure 3.22), sanders, saw, grinders, and others. By adopting the concept of using common product platform, Black & Decker was able to gain leadership in many consumer power tool markets, and at the same time, was able to reduce the complexity in its operation by using a single assembly program and common set of components (Katz, 2003).

![Black & Decker cordless drill series](image1)

**Figure 3.22** – Black & Decker cordless drill series. The uses of common platform enable the company to produce many variations of cordless drill customised to different users’ requirement (blackanddecker.com, 2013).

![Volkswagen's Modular Transverse Matrix](image2)

**Figure 3.23** - Volkswagen's Modular Transverse Matrix underlies the new Audi A3 and Volkswagen Golf (Credit: Volkswagen)

• **Automotives** – The automotive industry provides several examples of how to utilise one of the most expensive parts of a vehicle in a whole range of different models. One major example, the Volkswagen Group, which produces Seat, Audi, Skoda, and Volkswagen,
has been sharing platforms and managed to reduce significant cost in product development through this process (Cunningham, 2012). The MQB (Modular Transverse Matrix) platform is the latest platform model developed by Volkswagen to improve manufacturing efficiency (Refer to Figure 3.23). Another automobile company that has a highly innovative modular platform is Lotus Plc.

![Image of Airbus aircrafts]

**Figure 3.24** - Models of Airbus aircrafts share the same fuselage cross-section and significant component commonality (Airbus Industries, 2010)

- **Commercial aircrafts** – Most commercial aircraft manufacturers use common wings, nose, and tail components to leverage many models in their own range by using different fuselage modules to build aircraft of different lengths and passenger capacities (Refer to Figure 3.24). Increasing commonality across their models allows them to reduce the product development cycle time and tailor their models to their customers’ needs (Bador et. al., 2007). Besides, maximising the commonality of aircraft within its families will also make operations, training, and maintenance easier and more cost effective, thus contributes to the efficiency and operational flexibility of the aircrafts (Jones, 2010).
3.7 The Strategic Objectives of Industrial Design Innovation in Modular Product Design

Apart from the usual concerns of industrial design in achieving design integrity, cost-effective and creative design solution in new product development; some important strategic objectives for industrial design to meet the modular product strategies (Sanchez and Collins, 2001) have been identified. The strategic objectives are:

1. *The need to develop design concepts for more extensive product lines in order to increase product variety* – When the modularity strategy is applied to create greater product variety, the input of industrial design could be a new design concept for more extensive product lines (Refer to Figure 3.25).

2. *Refreshing product designs through styling or utility changes in visible components for technologically mature modular product* – In the situation where the product is mature, either in terms of concept, technology, and functions; the input of industrial design could focus mainly on refreshing the product design through styling and cosmetic changes in visible components (Refer to Figure 3.26). For a mature product that does not require changes in the styling aspect, the input of industrial design could focus on improving the users’ interaction and ergonomics by resolving and
satisfying the needs of the lead users based on the feedbacks provided by them. The lead users have experienced the needs and are particularly useful sources of data of the use environment.

Figure 3.26 – The variable styling of executive office chair

Figure 3.27 – Styling variations are needed to differentiate individual product models of digital camera within the total product family (Nikon UK Ltd., 2010)

3. Creating styling variations that can effectively distinguish individual product models within modular product family – Industrial design could also play a critical role in providing spatial styling variations in a product family line, while maintaining similar or improved degree of user interaction and ergonomics. Styling variations (Refer to Figure 3.27) can effectively distinguish individual product models within the
modular product families, while providing distinctive and unifying design theme to the total product family.

4. **Helping to bring a series of technologically upgraded product into the market in rapid succession** – The input of industrial design is a design concept that can be used to differentiate the multiple generations of technologically upgraded products that will be leveraged from a modular architecture. As technologically upgraded products components may not be visible to the users, industrial design has to provide effective differentiator of the new models via stylisation in order to communicate visually the improved technical performance of the new product (Refer to Figure 3.28). For technologically upgraded components with different sizes or shapes than their predecessors, the input of industrial design could be in the form of creating new spatial interfaces and configurations of features in the product design, in which they must be defined and created in ways that maintain the original design theme used to distinguish the overall product line. This is especially applicable to consumers’ electronics products where the product market cycle is generally around five to six months.

![Figure 3.28](image) - Flat screen television technology has developed rapidly from Plasma technology to LCD technology, and LED 3D technology with motion and voice command in 2010. The latest trend in flat screen television is curve screen as produced by Samsung Electronics Ltd. in 2013.
3.8 Industrial Design Innovation in Modular Rifle System Design

Modular architectures are essentially a tool for achieving a range of potential objectives and benefits (Sanchez and Collins, 2001). Within the context of the firearms industry, implementing industrial design in modular weapons system design will provide an essential support for achieving those objectives and benefits through innovative and cost effective approaches. The modular weapon system in this thesis is described as the modular assault rifle. It is a weapon system that permits the configuration of its component and accessories into several variants in order to meet specific military operations. In fact, modularity has become one of the major attributes that influence the purchase of rifles by the present military and law enforcement organisations (Sanborn, 2013). This fact is supported by the US Navy statement, which stated that one of the major requirements for procurement of new assault rifle for the navy is its modularity capability (US Department of the Navy, 2011). The emphasis on modular rifle design facilitates purchasing that can be done in bulk for the base rifle, as well as the many add-on modules, such as grenade launchers, laser pointers, scopes or torches, which can be interchanged with other base rifles.

Implementation of industrial design should be made from the initial stage of product development with industrial designers; contributing to strategic decision making by helping companies to understand the total design implication, relative market impact, and cost benefits of various trade-offs that could be made to define a new modular rifle architecture. Moreover, integrating industrial design from the earlier stage (for example – Idea Generation Phase) could result in the introduction of different and unfamiliar perspectives that may lead to higher level of creativity (Brown, 2008; Ravasi and Lojacono, 2005). Industrial designer’s contribution is also needed to define the specific product variations that could leverage from alternative modular product architectures a company could develop (Sanchez, 2002).

On top of that, industrial design is perceived as an innovative cost effective procedure to enhance the intrinsic value of the modular rifle design. When the modularity strategy is applied to develop new design concepts, the input of industrial design could be a new design concept for future rifles, or a special design concept for specific user or country. The special design concept would then be further developed to increase product variants to meet the requirement of each military branch, such as the Air Force, Navy, Army, Marines, Coast Guard, Reserve Corp, and many more. Additionally, each of the military branch would have their own specialised groups often known as the Special Operation Forces (SOF) group. The
regular assault rifle for this group must be capable of rapid transformation to meet specific operation requirement for the group, such as battle in close built-up environments, long distance sharp shooting, area reconnaissance, hostage rescue, and many more.

As mentioned in the previous chapter (Chapter 1, Section 1.6), the assault rifle is a mature product in terms of technology and functions. In refreshing product design through styling or utility changes in visible components, the input of industrial design could focus mainly on enhancement of body casing component texture and shades (colours), which are designed to match the location of operation, such as jungle, desert, snow, sea, and others. The new texture and shades could be designed to function as integrated camouflage without covering the rifle with extra layers of camouflage materials (Refer to Figure 3.29). For an assault rifle design that does not require changes in the styling aspect, the input of industrial design could focus on improving the users’ interaction and ergonomics. For example:- Resolving any ergonomic issues by introducing new material characteristics, which are lightweight, providing a comfortable touch or feel during operation, and easy maintenance. The other visible components are redesigned to support full ergonomic compatibility for both left-handed and right-handed users.

![Figure 3.29](image_url) – The new texture and shades design to function as integrated jungle camouflage without covering the rifle with extra camouflage materials (Copyrights © eHobbyAsia, 2013)
Industrial design could also play a critical role in providing spatial styling variations in a product family line, while maintaining similar or improved degree of user interaction and ergonomics. Styling variations can effectively distinguish individual product models within the modular product families, while providing distinctive and unifying design theme to the total product family. The SCAR (*SOCOM Combat Assault Rifle*) rifle, for example, is derived or developed from the M4A1 assault rifle platform (Refer to Figure 3.30). In order to meet the US (American) army special operation requirement, the body components are re-designed to the specific requirement specifications.

To boost the operation capability of the assault rifle, the base rifle body needs to be re-configured to integrate basic and advanced enhancement devices, such as the sight optics, grenade launcher, laser targeting device, and many more (Refer to Figure 3.31). Normally, these components are readily available in the market, but they could not be attached to the rifle if the attachment on the rifle is not compatible to accept these devices. Therefore, the understanding of rifle vital component layout is important for a designer to identify the suitable locations on the rifle body to design the attachments for additional devices without affecting the performance of the rifle. In this way, industrial design has provided effective differentiator of new models by re-designing the attachments. The attachment of different
devices grade on the rifle is one way to communicate visually the improved technical performance upgrade and the ability of the new rifle.

Figure 3.31 – Integration of operation boosting devices significantly enhanced the operation firepower capability and was aimed at accuracy of the concept rifle (Copyrights © Anemos Major, 2013)

Therefore, optimisation of industrial design methods provides innovative and cost effective design solution to create an ultimate modular weapons system. Nevertheless, rifle modularisation may not be subjected to just the components used, but adapted to be used as a multiple calibre modular service weapon that is capable of providing troops across the spectrum with a highly effective and multipurpose weapons system capable of undertaking any number of combat tasks through inherent flexibility of design and a number of innovative features.
Chapter 4

4. Industrial Design Analysis in Modular Product Design

Objectives: This chapter investigates the actual application of industrial design in modular product design and development process based on investigations conducted on actual practices. This investigation was conducted with the primary objectives of:

- Identifying the actual practices of industrial design application in modular product design.
- Identifying the actual needs of industrial design within the processes of a modular product design.
- Identifying the actual impact of industrial design within the processes of a modular product design.
- Developing fundamentals approach for industrial design application in a modular product design in the form of a framework.

4.1 Determining the New Industrial Design

Industrial design is a practiced methodology applied in the creation of products to satisfy the critical goals that encompass the aspects of product utilities, aesthetics, costs, production, and life cycle, in order to ensure their success for the benefits of both the producers and users. Besides, modern industrial design is derived from a complex amount of processes that involve extensive research into its definition, product architecture, technology, user needs, styling, and corporate strategies, by industrial design practitioners, research and development engineers/designers, product researchers, academia and scholar in the field of design, as well as product marketing and business managers. Comparable generic definitions of industrial design can be found in other literature, so are the theories behind it (Desai, 2007; Ulrich, K. & Eppinger, S.; 2004). The processes of industrial design have also been determined and are considered as one of the vital elements within the product design and development process. However, the processes of industrial design are not as intuitive as they
might seem, especially if the product under development has a highly complex composition, such as a product that adopts a modular architecture. As a modular product is created by integrating building blocks (modules) with specified interfaces, the design and development of such a product consists of sub-processes that demand added industrial design tasks within each block and the total integrated blocks. As specified in the four design principles of modular product design (Ito, 2008), industrial design should be considered in the separation, unification, connection, and adaptation aspects of the product. The main focus of this chapter describes the investigations of the actual tasks and several specified new added tasks that industrial design practitioners might have to carry out to meet the industrial design objectives and goals for a modular product. It must be mentioned here, however, that the investigations conducted had been purely on the design processes of tangible products or artefacts that hold the critical goals values as stated above. This investigation totally excluded modularity in design processes of production systems, software, machine tools, and cutting tools.

The results of the analysis are described qualitatively and are illustrated in graphs, as well as charts, in the following sections.

4.2. Investigation Process Perspective

![Figure 4.1 - Investigation process perspective structure]
Perhaps the most crucial aspect of the investigation within this methodology is the consideration of process perspective (Refer to Figure 4.1). The purpose of the process perspective is to check and determine the effectiveness of the research methodology used. The investigations must have a defined process structure that should enable the researcher to establish the appropriate processes to perform throughout the investigation. For the purpose of this research, several perspectives had been considered.

Before the investigation was conducted, the objectives of the investigation had been established in order to determine the selection of the processes. As mentioned in Chapter 2, Section 2.4.2, there are three (3) categories of survey modes used in the investigation, and each category might have different sampling parameters. Mapping the sampling parameters to each category is essential to ensure that accurate data are obtained from the correct sources. With that, four sampling parameters had been identified.

1. **Region** – Countries or locations where the surveys are intended to be conducted;
2. **Business** – Nature of business or activities the surveys are conducted on;
3. **Organisation** – Key sections/departments in the organisation where the surveys are intended to be conducted;
4. **Personnel** – Key personnel that are intended to be involved in the survey.

<table>
<thead>
<tr>
<th>Survey Modes</th>
<th>Region</th>
<th>Organisation</th>
<th>Business Type</th>
<th>Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Questionnaires</strong></td>
<td>United Kingdom; Western European; Malaysia</td>
<td>Product design; Product research; Product development</td>
<td>Defence; Transportation; Automobiles; Households; Electronics; Computers; Tools; Furniture; Toys</td>
<td>Industrial design personnel; Product development personnel</td>
</tr>
<tr>
<td><strong>2. Interviews</strong></td>
<td>United Kingdom; Western European; Malaysia</td>
<td>Product design; Product research; Product development</td>
<td>Defence; Transportation; Automobiles; Households; Electronics; Computers; Tools; Furniture; Toys</td>
<td>Industrial design personnel; Product design manager; Product development manager; Senior management personnel; Industrial design consultant; Product engineer</td>
</tr>
<tr>
<td><strong>3. Observations</strong></td>
<td>United Kingdom; Western European; Malaysia</td>
<td>Product design; Product research; Product development; Manufacturing</td>
<td>Defence; Automobiles; Electronics; Computers</td>
<td>Industrial design personnel; Engineering design personnel; Product assembly personnel</td>
</tr>
</tbody>
</table>

*Table 4.1 - Mapping of sampling parameters to the survey modes.*
The previous (Refer to Table 4.1) table shows the mapping of the sampling parameters to the modes of data collection. Construction of the survey modes relies on the objectives of the investigation. The most crucial aspect of the construction is determining the appropriate questions that would provide the answers needed to achieve the investigation objectives. The generic questions for all the survey modes had been standardized; however, the approach towards conducting the survey was suited to specific mode. For example, a question in the questionnaire form would be answered in the form, whereby a similar question for interview would be answered verbally. As for the observations mode, the generic questions in the questionnaire and interview modes were used as the key point of note in the observation study.

The execution of the observations modes was conducted within a designated time period, whereby the time period was kept flexible in order to gather responses that might come after the designated period. The acceptance of the survey responses was kept open throughout the research and new responses were added to the respondent count as the research progressed. The flexibility of the designated period was set for a maximum of one (1) year or throughout the first year period of this research. Besides, a post survey adjustment was conducted after the preliminary survey period. This task enabled the researcher to reconfigure the responses according to the appropriate sample group.

The final perspective to consider is the analysis and the evaluation of the collected data. Once the appropriate data are successfully gathered, they are then interpreted and transcribed into survey data in descriptive forms. In this research, the data were also represented in the form of tables, graphs, and diagrams. In order to ensure that these data were correct and acceptable, they were evaluated through subsequent presentation and discussion with the respective responding respondents. The validated data were filed and stored in both hardcopy and digital format, where external storage devices were essentially used to store back-up survey data. This procedure facilitated in easy retrieval of data to support further works in the research.

In addition, the design of the survey methods was initiated once the target scope and the primary questions had been established. In general (as described in Table 4.1), three survey methods were employed. Each of the methods contained similar introduction and objectives, followed by semi-structured questions, which formed the core of the survey contents. The final part of the methods was acknowledging the targeted respondents.
Although the contents of each method were similar, their configuration within the survey design had to be adapted to the different characteristics of each method. The questionnaire approach method consisted of two types of designs. One design is electronic or digitally based, while the other design is manual or in hard copy form. The electronic/digitally based questionnaire was sent through electronic mail (e-mail) in the form of an attached file. Meanwhile, the manual/hard copy version was submitted directly to the respondents in person or through postal delivery (Refer to Index 1, Pages 210 – 214, 215 – 222, 223 – 227, 228 – 234, and 235 – 240) for the actual questionnaire format. As for the semi-structured interview method, similar questions as in the questionnaire were used. The questions were, however, re-configured in the form of texts to suit the situation whereby they were asked directly through verbal communication between the interviewer (researcher) and the respondent (Refer to Index 2, Pages 241 – 248) for the actual interview question format. The third survey method was by means of observation of the actual product design and development process currently conducted by the selected organisations, with varied maximum duration as allotted by the organisations. The observation was focused on the standard activities practiced throughout the modular product design and development process. To facilitate the observation, the researcher also applied recording technologies, which included a digital sound recorder device, video recorder, and photography. During the observation process, several respondents showed discretions towards the task despite the assurance given by the researcher to abide by the survey principles practiced by the university. The researcher was only permitted the observations and recordings of the general design and development processes with close supervision by the project manager. However, the matter did not affect the data collection process as the discretions only concerned the design and technology aspects of the product, such as product styling, aesthetic value, and the operating technology embedded within the product.

4.2.1 Investigation of Quality Perspective

The emphasis on acquiring quality data had been vital throughout the investigation process. For the purpose of this research, the investigation of quality perspective was established and had been grouped into two (2) categories – Measurement and Representation (Refer to Figure 4.2). The quality perspectives included in the measurement group emphasised the design of the measurement approach, the execution of the measurement
approach, response, and revision of the response. Meanwhile, the representation group emphasised on aspects involving the targeted respondents, scope of respondents, actual respondents, and post survey revision.

![Figure 4.2 - Investigation of quality assurance measures](image)

### 4.2.2 Quality Perspective of Measurement Group

The design of the measurement approaches must be reviewed and validated before they were approved to be used in the survey. Meticulous discussions and presentation reviews of measurement design proposals were conducted by the researcher and the research supervisor to develop the most appropriate design that was concise and easily understood by the respondents in order to achieve the anticipated outcome. The measurement design proposals were also peer reviewed by selected members within the research organisation (Loughborough Design School, Loughborough University, United Kingdom) for preliminary corroboration of its design. References were also made from relevant survey methods and designs available from other researchers. The approved design was then implemented in the survey.

The next quality perspective monitored was the measurement errors during the survey. Measurement errors usually occur when the respondents provide inappropriate
answers due to difficulties in understanding questions, or mistakenly answering the wrong section or part of the questionnaire. Thus, the researcher is responsible for assisting the respondents should they have any difficulties in answering the questions in the questionnaire or interview. The respondents were asked to seek clarification from the researcher. The application of this measure ensured accurate responses from the respondents.

Besides, processing the responses has to be thorough and analytical. This task requires concentrated deliberation, thus any errors should be eliminated to avoid misleading or inaccurate findings. The responses need to go through a revision phase if the findings are suspected to be misleading or inaccurate.

4.2.3 Quality Perspective of the Representation Group

The scope of the investigation must be identified and established before the investigation structure is proposed and developed. Therefore, it is important for the researcher to stay within the scope of investigation to ensure the validity of the findings. Findings from outside the scope can confound the survey results. Besides, monitoring the coverage must be done constantly throughout the investigation, particularly in the selection of respondents. Therefore, the respondents were carefully selected from the targeted scope. The details of the respondents are shown in column 5 under the heading ‘Personnel’ (Refer to Table 4.1).

Furthermore, the researcher ensured that every effort put obtained the most out of the responses in terms of quantity and quality of the inputs. However, it is not always possible to get perfect inputs from the respondents as there are tendency that some questions in the questionnaires are left unanswered. In order to balance the effort, the researcher had employed other methods to increase the response rates. For the purpose of this research, the researcher employed several methods that included initiating advance correspondence with the target respondents through email and telephone contact to inform them about the research and its objectives. The respondents were also informed of the potential benefits and the advantages they could gain from the outcome of the research. The researcher also made several initiatives to conduct direct presentation to the respondents with the intention of creating friendly and mutual impression towards the survey exercise. The presentation method had proved to be a successful method as the respondents were more interested and
enthusiastic to participate as the visual explanation in the presentation provided better understanding of the research intention and objectives (Refer to Index 5, Page 277).

On the contrary, one of the most common reasons for lack of response encountered during the research survey had been refusal to participate in the survey due to project time constraints. During the first round of the survey (Category 1), forty (40) out of the fifty five (55) organisations (Refer to Table 4.2, Table 4.3) invited did not respond to the survey. Only a total of fifteen (15) responses were received. Table 4.4 lists the breakdown of the responses.

<table>
<thead>
<tr>
<th>Region</th>
<th>Organisation</th>
<th>No. of Organisations</th>
<th>Business Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom (UK)</td>
<td>1. Product design</td>
<td>10</td>
<td>Transportation; Automobiles; Tools; Furniture; Household</td>
</tr>
<tr>
<td></td>
<td>2. Product Research</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Product Development</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Western Europe</td>
<td>1. Product design</td>
<td>10</td>
<td>Defence; Automobiles; Electronics; Furniture; Toys</td>
</tr>
<tr>
<td></td>
<td>2. Product Research</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Product Development</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>1. Product design</td>
<td>2</td>
<td>Automobiles; Furniture; Computers; Household</td>
</tr>
<tr>
<td></td>
<td>2. Product Research</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Product Development</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2 – The details of organisations (Anonymous respondents) of various business types invited to participate in the research survey. Only 15 organisations agreed to participate in the survey

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of Organisations</th>
<th>% of Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td>Responses</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td>Non-responses</td>
<td>40</td>
<td>72</td>
</tr>
</tbody>
</table>

Table 4.3 – The number of respondents and percentage for Category 1 survey

<table>
<thead>
<tr>
<th>Organisations</th>
<th>Survey Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Questionnaire</td>
</tr>
<tr>
<td>1</td>
<td>√</td>
</tr>
<tr>
<td>2</td>
<td>√</td>
</tr>
<tr>
<td>3</td>
<td>√</td>
</tr>
<tr>
<td>4</td>
<td>√</td>
</tr>
<tr>
<td>5</td>
<td>√</td>
</tr>
<tr>
<td>6</td>
<td>√</td>
</tr>
<tr>
<td>7</td>
<td>√</td>
</tr>
<tr>
<td>8</td>
<td>√</td>
</tr>
<tr>
<td>9</td>
<td>√</td>
</tr>
<tr>
<td>10</td>
<td>√</td>
</tr>
<tr>
<td>11</td>
<td>√</td>
</tr>
</tbody>
</table>
Generally, it is rather difficult to determine and to understand the non-responses of the survey, therefore, a number of post-mortems had been conducted to identify and understand the reasons for the lack of response. The organisations were contacted directly through telephone calls and emails to find out their reasons for not supporting the survey. Many of the respondents revealed numerous reasons for not participating in the survey exercise (Refer to Table 4.5). Some of the most common reasons for not participating in surveys included lack of time for conducting and completing the survey. Besides, the organisations were inundated with many on-going and awaiting projects, which were pre-scheduled, and thus, accommodating surveys for a postgraduate research was not given any priority. Due to commitments in the ongoing projects, most organisations optimised their manpower, and therefore, resulted in the lack of relevant personnel to assist in the survey. Apart from these reasons, the organisations contacted were either less interested or not interested at all in the research as they felt that it had been insignificant to their business interest. Moreover, the usage of English language in the survey also limited the respondents as some of the organisations used other European languages, namely French, Dutch, and Spanish, while in Malaysia, the preferred language use is Malay.

<table>
<thead>
<tr>
<th>Reasons for non-response</th>
<th>Industry</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Not having the time to complete the survey</td>
<td>Transportation; Automobiles; Tools; Furniture; Households</td>
<td>UK, Western Europe, Malaysia</td>
</tr>
<tr>
<td>2. Ongoing project time constraints</td>
<td>Defence; Automobiles; Electronics; Furniture; Toys</td>
<td>Western Europe, Malaysia</td>
</tr>
<tr>
<td>3. Unavailability of personnel to assist in the survey</td>
<td>Automobiles; Electronics; Furniture; Toys</td>
<td>Malaysia</td>
</tr>
<tr>
<td>4. Research conducted is not significant to the respondents’ business interest</td>
<td>Transportation; Automobiles; Tools; Furniture; Households</td>
<td>UK, Western Europe, Malaysia</td>
</tr>
<tr>
<td>5. The survey was conducted in English</td>
<td>Defence, Automobiles; Tools; Furniture; Households</td>
<td>Western Europe, Malaysia</td>
</tr>
</tbody>
</table>

Table 4.4 – Breakdown of responses based on the survey methods

| 12 | √ |  |
| 13 | √ |  |
| 14 | √ | √ |
| 15 | √ |  |

Table 4.5 – Five (5) main reasons from organisation for non-response in this survey – categorised by industry and region
Based on the listed reasons, the researcher took several steps that might help to improve the non-response rate for future surveys. In order to reduce the effects of non-response, the researcher considered several approaches to adjust the survey results. The researcher had managed to identify five (5) common procedures for non-response adjustment (Sarndal et al., 2003; Madow et al., 1988). However, the researcher did not apply any of the procedures for non-response adjustment or adjusting the survey results. The researcher decided to retain and accept the actual results of the survey. The researcher maintained that the initial interaction between the interviewer (Researcher) and the respondents played a crucial role, and therefore, high consideration had been given to understand the dynamics of the interactions. Although the responses obtained had been only 28% of the anticipated number of respondents; the findings represented some significant results that contributed to the vital data needed for the next stage of the research.

4.3 Outcome of Investigation

This section of the chapter describes the core investigation issues. The results of the investigation were used to pre-determine and develop a concept for structuring the proposed industrial design framework.

4.3.1 Category 1 – The Perception of Industries towards Industrial Design in the Product Development Process

The surveys and investigations undertaken were to determine the major issues concerning industrial design application and the contributions in the process. The first set of questionnaires was dedicated to the fundamental investigations for the purpose of determining the current generic industry perception of industrial design in product design and development process.

The objectives of the investigation are stated below:

1. To find out the needs of industrial design in the strategic planning of a product.
To identify the actual involvement of industrial design in the product design and development process.

To investigate the anticipated future application of industrial design in product design and development.

To identify the actual demand of industrial design services provided by the industrial design practitioners/companies.

The details of the investigation outcomes are described in the following section. The investigation survey was conducted within the designated period of three (3) months with a flexibility of an additional two (2) months for late responses, which brought it to a total of five (5) months. A total of fifty five (55) product design and development organisations were contacted (Refer to Section 2.4.1, and Section 4.2.3.2), but only fifteen (15) organisations responded by answering the questionnaire and returning it to the researcher. For reference, the sample of the questionnaire is included in Index I (Page 210 - 214). Besides, a semi-structured interview was also conducted, which had been based on the questions provided in the questionnaire.

For the purpose of this research, the preliminary surveys were conducted in the first year of the research program. After the responses were obtained, the transcribing and interpretation tasks were immediately carried out. The data acquired were then translated, interpreted, and transcribed into qualitative data. The number of respondents was fed into Microsoft Excel software in order to generate representation graph of the data to better facilitate the interpretation of the findings. The following Sections describe the findings of the investigations.

4.3.1.1 Industrial Design in Product Strategic Planning

The first part of the questionnaire was designed to meet the requirement for Objective I (Refer to Index I, Page 210). The requirement was to find out the importance of industrial design in the organisations’ (Respondents) strategic product planning. The respondents were required to rate the industrial design functions based on its actual importance in comparison to other functions in the organisations’ strategic planning. The ratings method was adopted from the Likert item (Burns & Burns, 2008; John, 2008). The Likert-type item used by the researcher applied five (5) scales value to rate the importance of the functions (Refer to Table
However, the value assigned to the Likert item in this survey had no objective numerical basis, either in terms of measure theory or scale. The value assigned to each Likert item in the questionnaire form was simply determined through the decision based on a desired level of detail deemed appropriate by the researcher. Figure 4.3 below shows the findings obtained from the survey.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Likert-type Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>2</td>
<td>Undesirable</td>
</tr>
<tr>
<td>3</td>
<td>Maybe</td>
</tr>
<tr>
<td>4</td>
<td>Required</td>
</tr>
<tr>
<td>5</td>
<td>Highly Applicable</td>
</tr>
</tbody>
</table>

Table 4.6 – The 5 point Likert-scale rating was used to determine the importance of industrial design functions in strategic product planning.

Figure 4.3 - Application rating of functions in strategic product planning. Functions: 1-R&D; 2-Organisation; 3-Industrial design; 4-Manufacturing; 5-Marketing; 6-Information technology; 7-Engineering; 8-Sales
Based on the analysis results shown in Table 4.7, the researcher’s interpretations of industrial design perceived function requirement of the participating organisations are listed in the following:

- Industrial design is not a priority in strategic product planning as compared to research and development (R&D), information technology, and engineering function.
- Industrial design functions are generally placed as a supporting tool rather than one of the main tools in their strategic planning.
- The respondents (companies) rated and perceived industrial design as one of the potential aspects of their strategic product planning, but did not consider it as an essential element.
- The respondents (companies) would consider applying industrial design in their strategic product planning if the industrial design potentials are justifiable and could be totally ignored if they are not.

<table>
<thead>
<tr>
<th>Function requirement</th>
<th>Perceived importance of Functions</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scale</td>
<td>Description</td>
</tr>
<tr>
<td>1. Research and development</td>
<td>4</td>
<td>Required</td>
</tr>
<tr>
<td>2. Organisation</td>
<td>3</td>
<td>Maybe</td>
</tr>
<tr>
<td>3. Industrial design</td>
<td>3</td>
<td>Maybe</td>
</tr>
<tr>
<td>4. Manufacturing</td>
<td>3</td>
<td>Maybe</td>
</tr>
<tr>
<td>5. Marketing</td>
<td>2</td>
<td>Undesirable</td>
</tr>
<tr>
<td>6. Information technology</td>
<td>4</td>
<td>Required</td>
</tr>
<tr>
<td>7. Engineering</td>
<td>4</td>
<td>Required</td>
</tr>
<tr>
<td>8. Sales</td>
<td>3</td>
<td>Maybe</td>
</tr>
</tbody>
</table>

Table 4.7 – The table shows the results of perceived functions requirement in strategic product planning of participating organisations
4.3.1.2 Industrial Design Involvement in Product Development Process

The second section of the questionnaire was constructed to (Refer to Index I, Page 215) meet the requirement for Objective 2. The purpose of this section was to identify the industrial design involvement and relative timing towards product development process used by the organisations (Respondents). The survey was highly significant to investigate the phases of the product development process, where industrial design was applied the most. Several integrated activities within the product development process were identified and analysed. These activities included marketing, product research, product design, engineering design, quality assurance, manufacturing, component supplier chain, and maintenance. The timing of application or implementation of industrial design within the activities had been measured in percentage (%).

The graph in Figure 4.4 below illustrates the findings retrieved from the investigation.

![Bar graph showing the percentage timing of industrial design involvement within activities in product development process.](image)


The researcher’s interpretations of possible functions and involvement of industrial design in generic product development process are given in the following:
- Industrial design has a very minor application in the sales and marketing phase, thus indicating that the need is insignificant. Industrial design may involve the design of sales and marketing brochures and other printed advertisements. The industrial designer may assist the graphic designer to enhance the appearance of the product image better to grab the user’s attention.

- Industrial design involvement in product research is focused on the investigation of customer needs, and the analysis of product needs. Although the percentage is low, more industrial designers are involved in these areas as they are trained to understand the users’ requirements in order to create design proposals and products that are acceptable to users.

- Industrial design application in the product design phase is highly significant. Many organisations are beginning to realise the importance of industrial design within this phase. Accepting industrial design has a new emphasis on their design activities not only to enhance the aspects of styling and aesthetics, but also to improve the product based on users’ interactions and ergonomics factors in operating the product. Industrial design is also crucial in determining component interfaces interaction and enhancement of utilities aspects of the products.

- There are significant advantages in applying industrial design into engineering design. Although it may seem eccentric, the application of industrial design application within the engineering design model (Motte, 2008; Pahl & Beitz, 2007) is very much feasible. Creative inputs from the industrial designer into analysing product functions’ design, generation of design concepts, as well as design embodiment, are essential, particularly if the product is to meet the emotional requirements of the users.

- As quality assurance (QA) and quality control (QC) are mainly conducted on finished products, the involvement of industrial design is mostly limited to the design of inspection procedure standards.

- Designing manufacturing jigs and fixtures is the main concern of industrial design in the manufacturing phases. Jigs and fixtures are considered as products on their own, and therefore, the designing and prototyping of jigs and fixtures follow similar industrial design processes. The design, however, mainly implements and emphasises the
principles of ergonomics and functionality rather than aesthetics. Industrial designer may also be responsible for designing standard operation procedures (SOP) documents for the manufacturing of a product.

- The application of Industrial Design to the component supply chain is very minor, thus, indicating the need is insignificant. Industrial design involvement is probably limited to brochure design. Service design by trained Industrial Designer would be significant within this activity, particularly where human interaction is concerned.

- The utility aspects of a product are proposed and finalised during the design process. It is important for the Industrial Designer to consider the function of a product, particularly to facilitate maintenance, repair, and replacement of parts. The industrial designer’s involvement in planning and designing the configuration of critical components facilitates quick and easy access to components to be replaced (or repair).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Involvement %</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sales and marketing</td>
<td>10</td>
<td>Industrial design involvement is very small and minor, and limited to brochure design.</td>
</tr>
<tr>
<td>2. Product research</td>
<td>20</td>
<td>Industrial design is involved in customer and product needs analysis.</td>
</tr>
<tr>
<td>3. Product design</td>
<td>60</td>
<td>Industrial design is applied extensively throughout product design phases from conceptualization to prototype improvement.</td>
</tr>
<tr>
<td>4. Engineering design</td>
<td>40</td>
<td>Industrial design is applied in most aspects of engineering design except technology development.</td>
</tr>
<tr>
<td>5. Quality Assurance</td>
<td>20</td>
<td>Quality assurance mostly relates to finished product. Industrial design involvement is limited to the design of inspection procedure standards.</td>
</tr>
<tr>
<td>6. Manufacturing</td>
<td>30</td>
<td>Industrial design involvement is limited to the ergonomics of manufacturing layout, jigs and fixtures, and procedures of operation design.</td>
</tr>
<tr>
<td>7. Component supplier chain</td>
<td>10</td>
<td>Industrial design involvement is very small and minor, and limited to brochure design.</td>
</tr>
<tr>
<td>8. Maintenance</td>
<td>10</td>
<td>Industrial design involvement is very small and minor, and limited to manual design.</td>
</tr>
</tbody>
</table>

Table 4.8 – Justification of industrial design involvement in generic product development process among participating organisations.

In general, the outcome of the survey analysis revealed that the total involvement of industrial design in the product development process had been marginalised to an average of
only 25%. The percentage output indicated that the function of industrial design was less significant compared to the other functions in product development, except *Product Design* (Refer to Figure 4.4 and Table 4.8). Therefore, industrial design was mainly employed as a support tool for generating aesthetic values and human factors of the product. Besides, product organisations failed to recognise its full potential in product development; hence, industrial design did not constitute as one of the crucial aspects for the product development process.

### 4.3.1.3 Anticipated Industrial Design Application

![Figure 4.5 – Potential future roles of the Industrial Designer; the role of industrial design has diversified from the traditional ‘master of aesthetics’ to broader technical fields, which include product engineering and research.](image)

The third part of the questionnaire was designed to meet the requirement of *Objective 3*. The purpose of the third section was to find out the anticipated applications of industrial design in the organisations’ (respondents) future five (5) years of product development plans in comparison to the current application. This survey had been vital to investigate the current and future roles of Industrial Designer in the product development process. For the purpose of this research, five (5) potential roles were suggested. The research looked into the Industrial Designer performing the roles of *product researcher, product stylist, technician, creative leader,* and *product engineer* (Refer to Figure 4.5, Table 4.9). It is highly distinctive that the fields of technician, engineer, and product research are different compared to the field
of industrial design, but the transformation in the field of industrial design at present requires the Industrial Designer to be flexible and multi-skilled, as well as be able to perform non-traditional tasks that are not limited to aesthetics, users sensitivities, emotions, and human factors. The rising interest in industrial design from other domains of product development, particularly engineering and technology, has also changed the perception of engineers to learn industrial design creative skills. This has led the engineers, technicians, and industrial designers to perform interdisciplinary tasks in product design activities.

![Figure 4.6](image-url) – The graph shows the analysis output of the perceived current and future demands of industrial Design in product development. Roles: 1 – Product researcher; 2 – Product stylist; 3 – Technician; 4 – Creative leader; 5 – Product engineer

<table>
<thead>
<tr>
<th>Role</th>
<th>% of demand</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Product researcher</td>
<td>10</td>
<td>Future 40 There will be a significant increase in Industrial Designer being a product researcher.</td>
</tr>
<tr>
<td>2. Product stylist</td>
<td>80</td>
<td>Future 50 The perception of Industrial Designer as product stylist will decrease as their task within the more technical domains increases.</td>
</tr>
<tr>
<td>3. Technician</td>
<td>30</td>
<td>Future 10 The involvement of the Industrial Designer in hands-on technical repair or upgrading of products and prototypes will decrease as they are involved more in supervising task.</td>
</tr>
</tbody>
</table>
Table 4.9 – Justification for the current and future demands of industrial designer

Based on the analysis, the researcher formed the interpretations of the outcomes, as described below:

- Industrial Designers are not normally regarded as product researchers, but the services demand of Industrial Designer as a product researcher is anticipated to increase in the next five years. The increased demand indicates that Industrial Designers will be needed to conduct product research, particular in relation to the analysis of user needs, product trends, and intrinsic styling factors. Industrial design also plays a vital role in product planning research and defining product opportunity specification.

- The industries surveyed generally and typically perceived Industrial Designers as product stylists. Product design and development managers look at the Industrial Designer as expert in aesthetics and styling. Design teaching in universities also emphasises the importance of developing skills in product styling, which forms the foundation of industrial design studies. This perception has led to the high percentage in the current demand (Refer to Figure 4.6 and Table 4.9). However, in the next five years, this role is expected to change. This is relevant to the new emphasis in product design and development that design and development itself must be organized and collective. The cross-functional member of the research team should be capable of providing inputs to all the important design aspects, including styling, rather than leaving the thinking to only one expert.

- Industrial Designers are also considered as performing technician roles due to their current involvement in product prototyping and testing, as well as computer-generated drawing. Nonetheless, the percentage has been expected to decrease in the next five years due to the needs of Industrial Designers to perform more dedicated industrial
design responsibilities. The involvement of the Industrial Designer in hands-on technical repair or upgrading of products and prototypes will be reduced to supervisory role.

- An Industrial Designer can be considered as a creative leader in product design projects. This is due to their ability to generate creative product design solutions and this role is anticipated to increase in the next five years with the immergence of new product characteristics. Industrial Designers will have increased responsibilities in product design management, particularly in leading a research team of cross-functional disciplines. In normal practice, product design and development projects are led by a product engineer or design engineer, and often the output of the project is an engineer inspired or technically motivated design. A design project led by an Industrial Designer would result in a design that is more user-oriented, emphasising on visual sensitivity, which creates visual attractiveness for the product.

- Although Industrial Designers have different job scopes and responsibilities compared to engineers, industrial designers are increasingly needed in solving engineering problems through innovative industrial design approach. This has indicated that product engineers and Industrial Designers need to work together in order to create a successful product design team. Today, an increasing number of engineers are learning the skills of industrial design; leading the engineers to be experts in both fields.

4.3.1.4 Design Services provided by Industrial Design Practitioners and Organisations

The fourth part of the questionnaire was designed to meet the requirement of Objective 4 (Refer to Index I, Page 241). The purpose of this part was to identify the percentage of design services provided by that of the industrial design practitioners and organisations. The list of the design services is listed in Figure 4.7. These services were identified from the information provided by the respondents (Participating organisations). This survey had been important to investigate the current actual design services that industrial design practitioners and organizations are capable of undertaking. This investigation was also conducted to identify the scope of design services that normally contracted to the industrial design practitioners and organisations.
**Figure 4.7** – This graph shows the percentage of the identified services provided by industrial design practitioners and companies. Services: 1 – Product modeller; 2 – Product stylist; 3 – CAD/CAM; 4 – Plastic (polymer) product; 5 – Detail design; 6 – Electronic and software; 7 – Interface design; 8 – Product strategy; 9 – Industrial product

The graph in Figure 4.7 illustrates the findings of the investigation. The findings of design services provided by industrial design practitioners and companies, in percentage, are shown in Table 4.10.

<table>
<thead>
<tr>
<th>ID Services</th>
<th>Service %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Product modeller</td>
<td>80</td>
</tr>
<tr>
<td>2. Product stylist</td>
<td>100</td>
</tr>
<tr>
<td>3. CAD/CAM</td>
<td>70</td>
</tr>
<tr>
<td>4. Plastic product design</td>
<td>100</td>
</tr>
<tr>
<td>5. Product detailing design</td>
<td>80</td>
</tr>
<tr>
<td>6. Electronic and software</td>
<td>50</td>
</tr>
<tr>
<td>7. Interface design</td>
<td>80</td>
</tr>
<tr>
<td>8. Product Strategy</td>
<td>60</td>
</tr>
<tr>
<td>9. Industrial product</td>
<td>60</td>
</tr>
</tbody>
</table>

**Table 4.10** – Percentage of industrial design services, as recorded from the survey analysis
The researcher’s interpretations and justification of the outcomes are given below:

- **Product modeller** – Product modelling or prototyping is one of the most important services provided by industrial design practitioners/companies. The prototype models include mock-up, semi-operational, and fully operational prototypes. Most industrial design practitioners/companies have access to rapid prototyping facilities to generate the models.

- **Product stylist** – Typically for most product organisations, the term ‘industrial design’ is synonymous with styling. Therefore, the current practice of most product organisations is to engage industrial design practitioners/companies to conduct a styling process for their product to have aesthetically pleasing looks.

- **CAD/CAM** – Most industrial design practitioners/companies today have powerful computer facilities and software. The use of computer aided design (CAD) is common to generate a three (3) dimensional image of a product. Once the product has been finalized, a prototype can be produced with rapid manufacturing using the data directly from the CAD file.

- **Polymer product** – The designing of plastic or polymer products are popular jobs given to industrial design practitioners/companies. Most plastic/polymer products designed are product shell or outer casings. The prototypes of the products are also produced by rapid prototyping process using polymer materials.

- **Product detailing** – Most industrial design companies have cross-functional staff members, which normally consist of Industrial Designers and product engineers. Some projects may require a comprehensive product design and development service, thus product detailing is conducted with the collaboration of product engineers.

- **Electronic and software design** – Most industrial design practitioners/companies’ involvement in electronic and software design is restricted to casing or outer shell design, packaging design, and digital interactive design. Internal circuitries are normally supplied by the clients or by outsourced specialists.

- **Interface design** – Computer interface design is another service that is popular apart from product styling. As most industrial design practitioners/companies have powerful
computer workstations, the hardware is also utilised for user interface design, particularly for product organisation’s computer websites.

- **Product strategy** – Most industrial design practitioners/companies assist product organisations in developing product strategy by evaluating customer expectations of the product in terms of usability, product user interaction, and aesthetics. Normally, industrial design practitioners/companies that conduct this task will directly assume management of the product design project.

- **Industrial product** – Most industrial design practitioners/companies only undertake minor parts of the entire project. Such an example is designing the operator seat and control configuration of a high rise crane with emphasis on the operators’ ergonomics.

### 4.3.1.5 Investigation Summary

In the first part of the survey, the researcher identified that industrial design did not have a significant importance in strategic product planning. However, the researcher assumed that product organizations might consider implementing industrial design if the implementation can be justified to have significant benefits. Hence, thorough justification of industrial design benefits had to be presented to the product organisation’s senior management and decision makers by providing convincing evidence of the benefits. Besides, product organization management and decision makers must be informed about how industrial design aspects can provide those benefits.

In the second part of the survey, the findings revealed that industrial design application throughout the product design and development process was at an average of twenty-five percent (25%) with product design aspects constituting the highest percentage (60%). Most of the respondents agreed that industrial design should be applied throughout the process. However, there is currently no clear and structured approach for the industrial design application in each phase of the process. The absence of a structured approach has contributed to industrial design being applied at the stage when most of the technical aspects of the product have been finalised. This situation creates many design constraints as the Industrial Designer needs to work around the finalised product component configuration.
In the third part of the survey, the findings revealed that the current job scope of the Industrial Designer would change significantly from pre-dominantly that of a product stylist to encompass diverse job roles, including product researcher and product engineer. This condition will reduce the percentage of the product stylist role, but increases the number of tasks the Industrial Designers will be responsible for, such as product research, creative leadership and product engineering. These responsibilities could be carried out easily if a systematic approach is used to apply industrial design within the new scope of product development project.

In the fourth part of the survey, the findings revealed that a major proportion of the respondents for design services had been concentrated in product styling and plastic/polymer product design, which is closely related to product styling, as the design mostly involves styling of outer component shell or casings, which uses plastic/polymer materials. Most of the services provided by industrial design practitioners/companies were interconnected. However, electronic and software design services were normally not provided. Most industrial design practitioners/companies’ involvement in electronic and software design had been restricted to the casing or outer shell design, packaging design, and digital interactive design. Internal circuitries and software for operation of a product were normally supplied by the clients or from an external source.

4.3.2 Category 2 – The Importance of Industrial Design in Modular Product Development

This investigation focused on industrial design involvement in the modular product design and development process. The investigation was undertaken to find out the major issues concerning the involvement of industrial design and the contribution to the process. Therefore, a second set of questionnaire was developed for the investigation tasks (Refer to Index I, Page 241). The purpose of the investigation was to assess the importance of industrial design by determining the importance along the dimensions/perspectives of utility, aesthetics, product communication, cost, production, and product life-cycle, besides determining the potential areas and phases for industrial design application in the generic modular product design and development process. The scope of the survey/investigation is shown in Figure 4.8.
The objectives of the survey are as stated below.

- To identify the industrial design needs in modular product design/development based on the perspectives of utility, aesthetics, communication, costs, production, and life-cycle.

- To identify the relative application of industrial design within all phases of modular product design and development.

- To analyse the factors that justify the importance of industrial design in modular product design and development.

**Modular Product Development Process**

![Modular Product Development Process](image)

**Figure 4.8** – Investigation domain of industrial design application in generic modular product design and development process.

These survey investigations were conducted in the second year of the research program within a designated period of three (3) months with flexibility of additional two (2) months for late responses. A total number of fifty five (55) samples (companies) from the same list were approached and were provided with a set of questionnaires. A semi-structured interview was also conducted based on similar questions available in the questionnaire. The details of the investigation outcomes are described in the following section based on the identified objectives.
4.3.2.1 Industrial Design Needs in Modular Product Design

The first part of the survey investigation was conducted for the purpose of identifying the needs of the participating organisations for industrial design services in their modular product design/development activities based on the potential perspectives of utility, aesthetics, communication, costs, production, and life-cycle. This survey investigation had been vital to determine the industrial design services that were applied most (or frequently). Fifty five (55) respondents (from the same list of selected companies) were approached.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>No. of respondent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aesthetic and styling</td>
<td>20</td>
</tr>
<tr>
<td>2. Utility and ergonomics</td>
<td>15</td>
</tr>
<tr>
<td>3. Communication and corporate identity</td>
<td>10</td>
</tr>
<tr>
<td>4. Cost effective solutions</td>
<td>10</td>
</tr>
<tr>
<td>5. Facilitate production</td>
<td>8</td>
</tr>
<tr>
<td>6. Product life-cycle</td>
<td>3</td>
</tr>
</tbody>
</table>

*Table 4.11 – The needs of organisations for industrial design services in modular product design/development activities based on the identified potential perspectives.*

The table above (Refer to Table 4.11) portrays the findings of the industrial design needs according to the identified perspectives, and the number of respondents that considered the need. The same twenty (20) respondents approached participated in the survey. The graph in Figure 4.9 shows the outcome of the investigation.
Figure 4.9 – The graph shows the number of organizations that perceived the need of industrial design services in modular product design/development to meet the identified perspectives. Perspective: 1 – Aesthetic and styling; 2 – Utility and ergonomic; 3 – Communication and corporate identity; 4 – Cost effective solution; 5 – Facilitate production; 6 – Product life-cycle.

The researcher’s interpretations of the outcome are described in the following:

- **Aesthetics and styling** – All twenty (20) respondents stated that they applied industrial design to meet the aesthetics and styling needs of their products. The researcher, therefore, perceived that industrial design is crucial for product aesthetics and styling. The researcher also perceived that industrial design application is mainly to generate aesthetics and styling aspects for the respondents’ product, and the majority of the respondents regarded industrial design as the champion of the products’ appeal. Industrial design is mainly concentrated on creating the product form and user interfaces. The respondents also recognised the benefits of close coordination efforts between the Industrial Designers and engineers throughout this stage.

- **Utility and ergonomics** – Industrial design was considered important in utility and ergonomics needs for the respondents’ products. The researcher perceived that the respondents that applied industrial design to deliver these needs recognised that industrial design can provide them. These needs are extremely important for modular products as they often have multiple interfaces and features that may confuse the user. Besides, the respondents recognised that the Industrial Designers were also trained in the
aspects of utility and ergonomics, therefore, through industrial design, they could ensure that the interfaces and features of the product effectively communicate their function.

- **Communication and corporate identity** – As with any product-based company, the respondents also recognised that industrial design plays an important role in determining their identity. However, the researcher perceived that as some of the respondents did not produce user-driven products, product style is not crucial as compared to the respondents whose products are mostly user-driven. These respondents (user-driven products) need to maintain a consistent and recognisable appearance, and industrial design is needed to create and establish visual equity. The respondent professed that visual equity is directly related to the public’s perception of their company.

- **Cost effective solutions** – Industrial design is needed to provide creative cost effective solutions to product problems. The respondents recognised that industrial design does not only provide cost effective solutions during conceptualisation, but also facilitates manufacturing by suggesting other design details, such as surface finishes, simple but attractive components that minimise tooling, and manufacturing processes. The samples/respondents also agreed that many industrial design details can be implemented at no cost, especially if industrial design involvement starts from the beginning of the development process. However, 50% of the respondents stated that implementing industrial design increased their tooling and manufacturing cost. The researcher believed that this situation is due to the involvement of industrial design at the later stage when most of the technical aspects of the product had been established. Therefore, the involvement of Industrial Designers is purely on external styling, which might affect the overall structure or the configuration of features of the product, thus, increasing the cost of final tooling and manufacturing.

- **Facilitate production** – Less than half of the total samples/respondents agreed that industrial design can facilitate production or manufacturing of their product. While more respondents recognised that industrial design provides cost effective solutions through a creative and simple design approach, which can minimise production processes, the researcher perceived that the direct involvement of industrial designers in manufacturing is often confined to preparing and designing manufacturing processes instructions or guidelines, such as standard operation procedures and also standard inspection
procedures documents. Industrial designers may also assist in product inspection in order to ensure acceptable tolerance and quality, particularly for plastic products. Industrial designer may also be needed to find the best configuration of product assembly line for optimal ergonomics.

- **Product life-cycle** – Only a few respondents applied industrial design in relation to product life-cycle design. The researcher also perceived that this was due to the fact that most of the respondents did not apply product life-cycle analysis to generate new concepts for their product. As this technique is used most widely by companies interested in improving the environmental friendliness of their new products, most of the respondents did not emphasise this technique. The researcher also believed that the respondents were unaware that life-cycle analysis is applicable to design for all purposes. There is actually much industrial design potential in product life-cycle analysis as industrial design aspects in the product have many positive impacts from the time the product enters manufacturing as virgin raw materials until it is discarded or recycled after being used by customers. The industrial designer input is needed to ensure how well the product is designed at each stage within the product life-cycle.

### 4.3.2.2 Industrial Design application in Modular Product Design

The second part of the survey investigation was conducted to meet Objective 2. The purpose of the survey investigation was to identify the relative applications of industrial design within all the major phases of modular product design process currently used by the participating organisations. This survey investigation is essential to find out:

1. The specific **stages/phases of modular product design process** (Refer to Chapter 3, Figure 3.18) in industrial design are actually applied.

2. The desired need of industrial design application by the participating organisations.

Refer to Index I, Page 241 for the survey questionnaire used. The stages/phases of the modular product design process are described below.
Phase/stage descriptions

1. **Product planning/architecture** – The researcher emphasises the design and the manufacturing aspects of this stage. The product platform and architecture are considered. Assessing new technologies are normally conducted in this phase. The production constraints are identified and the supply chain strategy is set.

2. **Customer needs analysis** – There are four (4) tasks of *customer needs analysis*, which include:
   a. *Identifying the needs* – To find out precisely what the customers’ needs are and what customers really want in terms of functional needs and physical limitation by surveying prospective purchasers. This can be done by conducting a marketing study by using methods, such as interviews and questionnaires.
   b. *Investigation analysis* – The findings acquired from the customer needs survey are translated, analysed, and interpreted. These exercises are conducted to identify customers’ preferences of product features and performance (statement of recognized needs), which eventually will be used to form the product specifications.
   c. *Grouping and prioritization* – The customer needs are arranged into groups and prioritized according to their importance.
   d. *Satisfying customer needs* – Customer satisfaction is an important aspect to gain customer’s loyalty. This process involves communicating with customers to understand what they really need and translating the needs into a specification that can be met by products provided by the product organisation.

3. **Product Requirement Analysis** – There are two (2) tasks of product requirement analysis, which include:
   a. *Preparing functional Objectives* – Functional objectives are the basic operations or transformations that must be performed by a system to satisfy user’s primary needs.
   b. *Identifying operational functions* – The operational functional imposed functional and physical constraints on a modular product design.

4. **Product Concept Analysis** – There are three (3) tasks of product concept analysis which include:
a. **Product/concept generation** – This phase started with product or concept analysis followed by product or concept integration. Product analysis is the decomposition of the product into its basic functional and physical elements, whereas product integration is the arrangement of the basic elements into modules and integrated into a functional system.

b. **Identifying basic functional elements** – Product functional elements represent the intended behaviour (functions) of a product and its components. The elements are arranged accordingly into a number of logical configurations that will ensure the accomplishment of their intended combined function, which is called a working principle. A working principle defines the mode of action a product will perform.

c. **Identifying basic physical components** – The product is decomposed into basic physical components that when assembled together will accomplish the function of the product. The physical decomposition should result in the identification of basic components that must be designed or selected to perform the product function.

5. **Product Concept Integration** – There are five (5) tasks of product concept integration, which include:

a. **Defining System Level Specification (SLS)** – Refers to the one-to-one relationships between components with respect to their functional and physical characteristics. The functional characteristics result from the operations that components perform in order to contribute to the overall performance of the product, whereas the physical characteristics result from the configurations that implement the function of the product.

b. **Identifying SLS impact on GFR** – The system-level specifications may affect the general functional requirements as some specifications only help satisfy some general functional requirements, while others prevent the implementation of some desired general functional requirements. Therefore, the impacts of the system-level specifications on general functional requirements must be identified in order to develop products that meet the general functional requirements up to a satisfactory level.

c. **Identifying similarity index** – The level of components association is measured and used to group components into modules by incorporating the general
functional requirement weights, in addition to the system-level specification vectors and their impacts on the general functional requirements. This incorporation will provide a similarity index between the components.

d. **Optimising product elements and components** – This task can be achieved by using optimization models that maximise the sum of similarities by identifying independent modules that can be designed simultaneously. Several models are used, namely the p-Median model and the quadratic programming model.

e. **Grouping of Components** – Similar components are grouped into design families, and new designs can be created by modifying or re-configuring an existing component design from the same family. The task of component grouping requires careful planning and consideration. Classification and coding is considered to be the most powerful and reliable method of components grouping.

6. **Product Life-cycle Impact** – The product life-cycle generally involves three (3) stages. The stages include manufacturing, distribution, usage, final disposal, and retirement of the product. The product life-cycle impact is the result of product improvement that considers costs, customer value, manufacturing efficiency, ease of transport, storage, and environmental impact.

### Actual industrial design application in each Modular Design task

<table>
<thead>
<tr>
<th>Company</th>
<th>MD Tasks</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Product planning/architecture</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>2.</td>
<td>Identifying the need</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>3.</td>
<td>Investigation analysis</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>4.</td>
<td>Grouping and prioritisation</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>5.</td>
<td>Satisfying customers’ needs</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>6.</td>
<td>Preparing functional Objectives</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>7.</td>
<td>Identifying operational functions</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>8.</td>
<td>Product/concept generation</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>9.</td>
<td>Basic functional elements</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>10.</td>
<td>Basic physical components</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>11.</td>
<td>System level specification</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
12. Identifying SLS impact on GFR
13. Similarity index and matrix
14. Optimisation of element and components
15. Grouping of components
16. Production life-cycle impact

Table 4.12 – Actual application of industrial design in modular product design process of participating companies. The ticks in the corresponding boxes indicate that the respondents applied industrial design in the modular design tasks.

Fifty five (55) organisations (from the same list of selected organisations) were approached. A total of twenty (20) respondents out of the fifty five (55) organisations responded to the survey. Below are the findings of the respondents’ actual industrial design application in all the stages/phases of the modular product design processes. The findings of the investigation are shown in Table 4.12 and Figure 4.10.

![Actual industrial design application in modular design tasks by participating organisations](image)

Figure 4.10 – This graph shows the number of companies performing industrial design in modular design tasks

Below are the findings of the survey investigation that depict the same respondents’ desired industrial design application in all the stages/phases of the modular product design processes. The findings of the investigation are shown in Table 4.13 (highlighted in grey) and Figure 4.11.
**Desired need for industrial design application**

| MD Tasks | Company | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|----------|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|
| 1. Product planning/architecture | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2. Identifying the need | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 3. Investigation analysis | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 4. Grouping and prioritisation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 5. Satisfying customers’ needs | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 6. Preparing functional Objectives | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 7. Identifying operational functions | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 8. Product/concept generation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 9. Basic functional elements | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 10. Basic physical components | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 11. System level specification | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 12. Identifying SLS impact on GFR | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 13. Similarity index and matrix | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 14. Optimisation of element and components | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 15. Grouping of components | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 16. Production life-cycle impact | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Table 4.13 – Desired (highlighted) application of industrial design in modular product design process of participating companies.

**Figure 4.11** – This graph shows the number of companies desiring industrial design in the identified modular design tasks.
4.4 Factors that Justify the Importance of Industrial Design in Modular Product Design – A Qualitative Analysis

For the purpose of the analysis, any design approaches conducted in the modular design tasks that relate to the aspects of user needs are described as “industrial design”. This is rationalised by the fact that the most immediate purpose of industrial design is meeting the user’s psychological and physical needs. The result of the first survey indicated that most of the participating organisations (mentioned as respondents) implemented industrial design in at least one (1) modular design task listed in the questionnaire. The tasks where industrial design is most implemented are shown in Table 4.10 and Figure 4.11. Based on the analysis, the respondents applied industrial design in the areas where psychological sensitivity influenced the decision. For example, in the customer needs investigation tasks, a project member had to conduct investigations to find out precisely what the customers really want in terms of emotional and functional needs, and physical limitations that they expect from the product. These needs are generally measured through the users’ acceptance of the products’ features.

In addition, further investigation into the responses revealed that the respondents applied industrial design informally (in which the respondents themselves were unaware of), particularly at the concept generation phase due to sensitivity to aspects of aesthetics and feasibility. These practices, although apparently depicting some industrial design background, actually cannot be acknowledged as industrial design, rather this approach could be described as applying the mechanism of silent design (Gorb and Dumas, 1987) since the respondents did not invest noticeably in industrial design. The modular design tasks where industrial design was not applied had been considered as the “areas of uncertainty”, whereby the respondents were unsure of applying industrial design within those tasks although there may be potential for it.

The second part of the survey investigated the desired industrial design application in all the phases of the modular product design process. The result of the investigation revealed that the respondents considered the application of industrial design in more tasks within the modular design process. The significant increase in industrial design applications are shown in Table 4.11 and Figure 4.12. The desire for industrial design was also seen in tasks that are normally associated to the aspects of engineering. This indicated that the respondents
anticipated the application of industrial design as a creative approach to provide cost effective solutions to engineering problems. Optimisation of modular elements and components, for example, is one of the engineering tasks where industrial design could be applied. However, the task of tackling engineering problems through industrial design could be difficult if it is done by an industrial designer as they are likely to possess little knowledge of engineering. This issue could perhaps be solved by training design engineers in the aspects of industrial design. The example above might not involve the aesthetic aspect of industrial design, but certainly seems to require functionality and feasibility aspects where an industrial design trained design engineer (or vice versa) would be the most appropriate person to handle the task.

Based on the analysis results, it is believed that there are significant evidences to justify industrial design as one of the essential strategic tools in the modular design process. However, this strategic tool could not be formally applied due to the unavailability of a formal industrial design framework and systematic methodology to assist product organisations in applying industrial design within their modular design process. As described in the previous chapters, industrial design historically has roots in the philosophy and practice of the crafts movement, and the invention of styling as a way of increasing product sales. Modular product design, on the other hand, remained in the discipline of engineering, while in academia, industrial design is still very much considered as a creative applied art. However, the components of industrial design are now emerging in engineering and technology, often where the artistic component has given way to more practical industry-oriented question (Tovey, 1997; Cross, 2001). Industrial design and engineering modular product design both have input into product design processes and manufacturing, as it can be seen from the results obtained from the survey, but the contribution of engineers and industrial designers depends on the relative importance to technical, aesthetic, and ergonomic factors.

The surveys concluded with a realistic compromise that showed the best of both disciplines – arts and engineering (Refer to Table 4.13 and Figure 4.11). The new framework functions as a hybrid solution as it blends together technical and creative aspects to give commercial merit to both disciplines. The ‘design process’ between an ‘engineer’ modular design and industrial design shares common ground, but has a lot of differences (Cross, 2001; Melles and Kuys, 2010). These differences are where the design components must be made
similar in the form of a standard practise. Therefore, a formal framework for ‘Industrial design – Modular product design’, when established, will outline the standard practice and the guiding principles, plus the key structural elements for precise and effective application of industrial design methodology within the modular product design process. This framework is fundamentally vital to optimise the benefits of industrial design in modular product design in meeting the users’ requirements for efficient product usability, distinctive aesthetics and appeals, costs benefits, product manufacturing, and the management of product life-cycle.

The next chapter describes the details of the framework and how it leads to the construction of an industrial design application standard that eventually becomes one of the reference benchmark for industrial design in new modular product design project.
Chapter 5

5. InDFM Construct

Objectives: Having analysed the application of industrial design in the existing product design process and the potential it has to support modular product design, this chapter examines the methodology for developing the InDFM and also explains the detailed mechanism of the framework. These are performed through:

- Identifying the key elements for construction of InDFM
- Understanding the operationalisation of industrial design in InDFM
- Experimenting the standard

5.1 Framework Objective

The framework supports the application of industrial design in any modular product design and development processes and it is flexible to adapt to any changes within the used and future modular design and development process stages. The objectives of the proposed framework are specified in the following:

- *As industrial design optimisation tool* – The framework provides a method to optimise the potential of industrial design benefits in modular product design and development with emphasis on the innovativeness of the industrial design approach.

- *As industrial design management tool* – The framework supports the integration of the industrial design process into the existing modular product design process through defined management structures and practices set up to deploy industrial design, as well as to optimise industrial design outcomes.

- *To collect and transmit industrial design data* – The framework supports the systematic input of industrial design data into the modular product design process, as well as supporting systematic distribution of the data throughout the process to achieve innovative and creative product properties outcome.
• To enhance new product design process – The framework supports the enhancement of new modular product design process through the addition of a clearly defined structure containing innovative design and development elements. Additionally, the framework is adaptable to changes within any modular design process stage.

5.2 Defining the Taxonomy of InDFM

The key elements in the creation of the InDFM taxonomy are listed in Table 5.1 below. The overview of each of the key elements is described in the following sections. The use of these elements in creating the taxonomy is also described in each section. These key elements form the backbone of the framework.

<table>
<thead>
<tr>
<th>Key Elements</th>
<th>Stage and description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ISO 9001 Design and development</td>
<td>Customer requirement; design input; design; design output; design validation; product release.</td>
</tr>
<tr>
<td>2. Industrial design process</td>
<td>Customer needs investigation; conceptualization and design; preliminary refinement; final concept selection; industrial design product drawing; co-ordination.</td>
</tr>
<tr>
<td>3. Modular product design process</td>
<td>Customer needs analysis; product requirement analysis; product concept analysis; product concept integration.</td>
</tr>
<tr>
<td>4. Principles of modular design</td>
<td>Separation of modules; unification (standardization) of modules; connection of modules; adaptation of modules.</td>
</tr>
</tbody>
</table>

Table 5.1 – Key elements of InDFM taxonomy

5.3 Mechanism of InDFM

The InDFM consists of a clearly defined structure (Refer to Figure 5.1) constructed with integration of the key elements arranged within the ideal ISO 9001 Design and development process (one of the key elements of InDFM taxonomy; other elements encompass the industrial design process, the modular product design process, and the principles of modular product design – Refer to Chapter 3, Section 3.10) The integration of all the elements in InDFM is completed through applications (or adaptation) of the industrial design measures to meet the specified objectives of the framework (Refer to Section 5.1).
Figure 5.1 – Overview of InDFM mechanism environment

Figure 5.2 – The InDFM structure
The structure (Refer to Figure 5.2) is shown as the general configuration and should be completely understood by those involved and responsible for project management, design, and engineering. Any actual activity and integrated process are more complex than the one shown.

Figure 5.3 – InDFM detail: formed with integration of key elements clearly shows how each element interacts within the new process environment.

The process starts with establishing the classification of *industrial design measures* \(\textit{or operationalisation}\) (Refer to Chapter 3, Section 3.10), which is generally decided by the top management with inputs from industrial design team. This group will have the control over the decision on whether industrial design is needed within the specific stage of product design. The activities of implementing industrial design measures are conducted within the product development organisation (represented by a dashed line). Beyond this boundary is the external customer of the released product. Industrial design measures will be adopted or implemented immediately within the modular product design process. The implementation process requires the industrial design measures to be aligned with the modular product design stages (Refer to Figure 5.3) in order to determine the appropriate stage where industrial design aspects should be. Emphasis must be given to industrial design outcomes as they contain the creative industrial design aspects that are concerned directly with the design outlook and functionality of the tangible product. The execution of these measures must
adhere to the modular design principles so that it does not jeopardise the modular characteristics and performances of corresponding modules.

5.3.1 Code Definitions

In order to facilitate the implementation of the framework, the researcher had established predefined codes for easier identification of tasks and requirements. There are two (2) categories of codes: 1. Codes for the implementation process (Refer to Table 5.2), and 2. Codes for standard evaluation (Refer to Table 5.3). The codes for use in the implementation process consist of codes for the Modular product design process (MPD), Generic industrial design process (ID), and Industrial design critical dimension (CD). These codes are then followed by figure and sub-figure. The codes for the standard evaluation consist of codes for industrial design measurements (Operationalisation), industrial design priority level (P), and quality control and assurance priority level (PQ). The uses of the codes are translated in the following sections.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modular product design process</strong></td>
<td></td>
</tr>
<tr>
<td><strong>MPD1</strong></td>
<td>Project Definition</td>
</tr>
<tr>
<td>MPD1.1</td>
<td>Classification of modular product development project</td>
</tr>
<tr>
<td>MPD1.2</td>
<td>Identifying opportunity</td>
</tr>
<tr>
<td>MPD1.3</td>
<td>Evaluate and prioritize project</td>
</tr>
<tr>
<td>MPD1.4</td>
<td>Allocation of resource and planning time</td>
</tr>
<tr>
<td>MPD1.5</td>
<td>Complete pre-project planning</td>
</tr>
<tr>
<td><strong>MPD2</strong></td>
<td>Customer Needs Analysis</td>
</tr>
<tr>
<td>MPD2.1</td>
<td>Identifying needs</td>
</tr>
<tr>
<td>MPD2.2</td>
<td>Analysis approaches</td>
</tr>
<tr>
<td>MPD2.3</td>
<td>Needs grouping and prioritisation</td>
</tr>
<tr>
<td>MPD2.4</td>
<td>Satisfying customer needs</td>
</tr>
<tr>
<td><strong>MPD3</strong></td>
<td>Product Requirement Analysis</td>
</tr>
<tr>
<td>MPD3.1</td>
<td>Functional objective</td>
</tr>
<tr>
<td>MPD3.2</td>
<td>Operational and general functional requirement</td>
</tr>
<tr>
<td>MPD3.3</td>
<td>Requirements importance assignment</td>
</tr>
<tr>
<td><strong>MPD4</strong></td>
<td>System Decomposition</td>
</tr>
<tr>
<td>MPD4.1</td>
<td>Product/Concept generation</td>
</tr>
<tr>
<td>MPD4.2</td>
<td>Decomposition – functional elements (technical – engineering)</td>
</tr>
<tr>
<td>MPD4.3</td>
<td>Decomposition – physical elements (physical form design)</td>
</tr>
<tr>
<td><strong>MPD5</strong></td>
<td>System Optimisation</td>
</tr>
<tr>
<td>MPD5.1</td>
<td>System level specification (SLS)</td>
</tr>
<tr>
<td>MPD5.2</td>
<td>Identification of SLS impact on GFR</td>
</tr>
<tr>
<td>MPD5.3</td>
<td>Components similarity (index and matrix)</td>
</tr>
<tr>
<td>MPD5.4</td>
<td>Modules (and sub-system) component grouping &amp; optimisation</td>
</tr>
<tr>
<td><strong>Generic industrial design process</strong></td>
<td></td>
</tr>
<tr>
<td>ID1</td>
<td>Investigation of customer needs</td>
</tr>
<tr>
<td>ID2</td>
<td>Conceptualisation</td>
</tr>
<tr>
<td>ID3</td>
<td>Preliminary refinement</td>
</tr>
<tr>
<td>ID4</td>
<td>Final concept selection</td>
</tr>
<tr>
<td>ID5</td>
<td>ID product drawing</td>
</tr>
</tbody>
</table>
5.4 Structuring InDFM

In order to understand the implementation notion of InDFM, the researcher had put all the vital elements that made the framework within a single anthology (Refer to Figure 5.1, 5.2). It can be clearly seen that the process of modular product design and the generic industrial design are rather unrelated in most phases. This is mainly due to the fact that the integration of the industrial design process into modular product design could not be conducted simply based on the numerical order of phases. The aspects or (and) activities of
the industrial design process may be applied to any phase of the modular product design process depending on the kind of modular product that is developed. Generally, the execution of industrial design customer needs analysis could be done in the customer needs and product requirement analysis phase of the modular product design. However, this process could not be integrated into the next phases of modular product design as these phases are specifically dedicated to system design. The investigation of customer needs in the industrial design process is generally defined as the investigation into the characteristics of the psychological needs of customers. These characteristics then become the elements that influence their preference. The design conceptualization process is comparatively technical in nature, thus it can be easily integrated into the concept analysis phase of modular product design. The design conceptualization process may also be incorporated into the concept integration (modular system optimization) phase. Similarly, the following industrial design processes involving preliminary refinement, final selection of concept, industrial design drawing, and coordination of team members may be integrated in either the concept analysis or concept integration phase of the modular product design process.

Besides the integration of the two processes mentioned above, the measures (or operationalisations) of industrial design also need prior consideration before the process integration can take place. The industrial design measures are used as a guideline to identify the appropriate implementation point along the modular design process path. It is rather peculiar to see the industrial design measurements (*Emphasis*) start from the first phase of the modular product design process whilst the generic industrial design process starts from the second phase. The industrial design measurements are variables that describe the quantity of implementation, whereas the generic industrial design process is defined as the steps towards producing the outcomes of the industrial design. Therefore, it is significant to consider the industrial design emphasis during modular product definition so the decision on industrial design within the entire process could be defined and established. The integration of the two processes is conducted based on the modular design principles, within the ideal ISO 9001 Design and Development Process standard. Once the implementation notion is understood, it is now possible to point out accurately the potential of industrial design in the modular product design process.
5.5  InDFM Standards

In order to support the users of the InDFM, a set of implementation standards is used. These standards are intended to provide an appropriate and practical approach for applying industrial design within a generic modular product design process based on the core activities within each phase. Each standard is presented as a checkpoint table for reference. The checkpoints used in these standards enable the user to determine and respond to the requirements needed in order to accomplish the industrial design input tasks. These checkpoints also facilitate the user in establishing the fundamental objectives of utilizing industrial design in their development process by providing a breakdown of subjects that need prior consideration.

5.5.1  InDFM Standards – Objective

The InDFM technical standards are intended for the purpose of providing the appropriate practical approaches for utilizing industrial design in a generic modular product design process, based on the core activities within each phase. These standards set out to meet the following objectives:

1. To identify the core activities within each phase of the modular product design process;

2. To identify and understand the localised elements that influence the acceptance of product features and characteristics for specific market;

3. To determine the key industrial design inputs from the Industrial Designer for each core activity;

4. To suggest approaches on inputs for each core activity;

5. To determine the *application priority level* of industrial design for each core activity;

6. To specify the anticipated results and possible consequences if industrial design is not applied;
7. To determine personnel to coordinate and liaise with the Industrial Designer;

8. To determine the quality control (QC) and quality assurance (QA) priority level of the application of industrial design;

9. To determine the quality control (QC) and quality assurance (QA) priority level of the coordination with the Industrial Designer within the project team member; and

10. To specify justifications for every task involved.

5.5.2 Standards Checkpoints

Each standard is provided into a checkpoint table for reference. The following checkpoints require actions by both existing and new project members. The project members that are involved in each phase of the project must comply with the checkpoints by making the specified commitment as suggested in the standards.

The checkpoints used in these standards enable the user to determine and respond to the requirements needed in order to accomplish the industrial design input tasks. These checkpoints also facilitate the user to establish the fundamental objective of utilizing industrial design in their development process by providing breakdown of subjects that need prior discernment. There are three (3) checkpoints that must be complied with. The checkpoints include:

**Checkpoint A – Input**

This checkpoint sets out the following:

1. Core activities within each phase of the modular product design process
2. Key ID inputs from the industrial designer for each core activity
3. Suggested approaches of inputs for each core activity
4. Application of priority level of ID for each core activity
5. Justification of the activities.

The checkpoints are based on the generic core activities that have been determined as the main steps in the modular product design process. The elaboration of checkpoint A is described as follows (Refer to Table 5.4):

<table>
<thead>
<tr>
<th>Core activity</th>
<th>Activity code</th>
<th>Industrial design input</th>
<th>Approach</th>
<th>Justification</th>
<th>Priority code</th>
</tr>
</thead>
<tbody>
<tr>
<td>All tasks related to each phase of modular product design (MPD)</td>
<td>All codes of tasks/activities within each phase of MPD</td>
<td>All inputs that are provided by industrial designer to facilitate industrial design application</td>
<td>All the approaches on how to implement and achieve the inputs.</td>
<td>All the justifications on the needs of industrial design within the activity.</td>
<td>Codes of industrial design input priority.</td>
</tr>
</tbody>
</table>

Table 5.4 – Detailed elaboration of specific columns for Checkpoint A

Checkpoint B – Benefit and consequence

This checkpoint sets out the following:

1. Anticipated results
2. Possible consequences
3. Justifications of the activities

<table>
<thead>
<tr>
<th>Activity &amp; Code</th>
<th>Anticipated result</th>
<th>Possible consequence</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>All codes of tasks / activities within each phase of modular product design (MPD)</td>
<td>All the possible positive outcomes of industrial design application within each MPD phase</td>
<td>All the possible negative outcomes of non-application of industrial design within each MPD phase</td>
<td>All the justifications on the possible positive outcomes of industrial design application and the possible negative outcomes of non-application of industrial design.</td>
</tr>
</tbody>
</table>

Table 5.5 – Detailed elaboration of Checkpoint B
The checkpoints table (*Checkpoint B*) presents the anticipated results from the application of industrial design and the possible consequence if industrial design is not applied in the related activities that are required in this phase. The checkpoints also point out the justifications of the two groups of outcomes (Refer to Table 5.5).

**Checkpoint C – Coordination**

This checkpoint sets out the following:

1. Suggested personnel to coordinate and liaise with the Industrial Designer

2. Suggested quality control and assurance priority level of the input of ID and coordination within the project team

3. Justifications of the activities.

The checkpoints table (*Checkpoint C*) represents the interaction of industrial designers and other members of the development team. These checkpoints provide suggestions to who the industrial designers should coordinate and liaise with when executing the activities. The activities and coordination should be constantly reviewed to maintain the quality of the coordination, effectiveness, and efficiency. These checkpoints also provide justifications of the coordination (Please refer to Table 5.6 and Index 3).

<table>
<thead>
<tr>
<th>Activity &amp; Code</th>
<th>Coordination/Liaison</th>
<th>QC/QA Priority</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>All codes of tasks / activities within each phase of modular product design (MPD)</td>
<td>All lists of possible parties involved in the new project.</td>
<td>All codes of quality control / assurance appropriate to each phase within each phase.</td>
<td>Justification of industrial designers’ coordination / liaison with other team members or organization involved in the project.</td>
</tr>
</tbody>
</table>

*Table 5.6 – Detailed elaboration of Checkpoint C*

After conferring with the checkpoints of the standards on each phase, the user is required to use the verification checklist table to confirm if the specified activities are currently being practiced within the company’s existing development process. The result of
the verification could determine the final decision of considering the feasibility of industrial design in each phase within the modular product development process the company is using. The checkpoints and the checklist require actions by senior management and both existing and new project members. The senior management and project members that are involved in each phase of the project must fulfil the checkpoints by giving specified comments as suggested in the standards.

5.6 Implementation of Framework

The researcher suggested that the use of coding should be conducted concurrently with the use of the industrial design measures (operationalisation). The combined used of the codes and the measure factors will provide a perceptive awareness of the anticipated potential positions of industrial design attributes and values throughout the design process. Using the pre-defined codes (Refer to Section 5.2.1), the project team members can now systematically identify and implement industrial design accurately in the appropriate phase along the modular product design process (Refer Figure 5.4).

![Figure 5.4 – Generic application details: showing the phases (Marked by MPD’s) where industrial design (Marked by InDFM) can be accurately and systemically applied. Industrial design measures are indicated below the phase’s row.](image)

The use of simplified coding facilitates rapid memorisation of industrial design tasks plus activities by the team members. This approach may also be used during brainstorming and focus group sessions. The coding is written and recorded by using a table format as
shown in Table 5.1. The table contains: 1. MPD Phase, 2. MPD Task, 3. ID Process, 4. ID Critical dimension, and 5. ID Measures. These elements form the key requirements needed to identify industrial design in each phase. The details of the implementation process are explained in the following sections based on a simulated user-driven modular product design project as an example. The examples are also illustrated by Tables (Refer Table 5.7) according to each stage of the modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
</table>

Table 5.7 – Application of industrial design implementation table format

5.6.1 Product Definition Standards

The project definition phase (Code: MPD 1) is the first phase of modular product design process. This is also the first phase where industrial design consideration is analysed. Within this phase, five (5) tasks or activities are normally conducted. The activities include: 1) Classification of modular product development (Code: MPD 1.1), 2) Identifying the opportunity for the modular product development (Code: MPD 1.2), 3) Evaluation and prioritisation of the project (Code: MPD 1.3), 4) Allocation of resources and planning time (Code: MPD 1.4), and 5) Completion of pre-project planning (MPD 1.5).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 1</td>
<td>MPD 1.1, 1.2, 1.3, 1.4, 1.5</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>EM</td>
</tr>
</tbody>
</table>

Table 5.8 – What the application of industrial design in Phase 1 (MPD 1 – Modular product definition) of the modular product design process could look like; this table represents all the five (5) activities in MPD 1.

Generally, there is no industrial design aspect involved in this phase of modular product design, except for the operationalisation consideration where industrial design emphasis (EM) could be discussed and determined by the project management team (Refer to Table 5.8). As mentioned in Chapter 3, Section 3.10, industrial design emphasis is connected
with a company’s strategic planning whereby the decision to include industrial design in their product design activities is discussed, as well as the degree to which industrial design is put under consideration. However, other industrial design aspects could be employed depending on the category of modular product that is going to be developed. Take for example, a kind of modular product that is highly user-driven, industrial designers could be involved in the opportunity identification exercise as they are also considered as experts in identifying and defining the user needs for a new product. However, if the product is technology-driven, then the involvement of engineers is needed to identify the opportunity of product development by exploiting the availability of the new technology. Therefore, once the project is categorically specified, the emphasis of industrial design could be established.

5.6.2 Needs Analysis Standards

The needs analysis phase (Code: MPD 2) involves four (4) tasks. The tasks are:

1. Investigation of needs (Code: MPD 2.1)
2. Analysis approach (Code: MPD 2.2)
3. Needs grouping and prioritisation (Code: MPD 2.3)
4. Satisfying customer needs (Code: MPD 2.4)

These tasks are elaborated in the following paragraphs.

Investigation of Needs (Code: MPD 2.1)

The second phase (Code: MPD 2) of the modular product design process involves the investigation into the needs of users. Generally, the product definition phase (MPD 1) provides the project team with an ill-defined problem, normally one of a mere suggestion that there is a need for a product to perform a specified function. Therefore, the first task of the project team is to identify what the needs are. Once the needs are identified, the data are then used to describe the product fully in terms of functional needs and physical limitations. These two factors will then be used to form the product specification. The Industrial Designer involvement in this task is to source information not only from potential customers, but also from others, such as the company for which the design is being made, competitors, and the
relevant authorities that can impose restrictions on the product. The industrial design task in this phase is investigation into the customer needs (ID 1).

As described earlier, part of the expertise of the Industrial Designer is identifying and understanding user needs. The user needs are elaborated, but in the context of industrial design; the user needs can be categorized into two main concerns – *usability* (functionality) and *aesthetics* (visual appeal). These two aspects are viewed as the key outcomes of industrial design, which are only attainable through consideration of the industrial design critical dimension (Refer to Table 5.1). As observed in Table 5.9, the investigation of product usability (CD 1) involves all the usability attributes. The investigation of product aesthetics (CD 2) also involves all the aesthetics attributes. As for the product cost (CD 3), investigation is only conducted to identify the need for cost benefits and trade-off (CD 3.1). Investigation on the appropriate use of resources (CD 3.2) is not significant as the specification of resources will be decided by the design management team based on available funds. In normal circumstances, general users are more concerned about the product usability and aesthetics rather than the appropriate resources used to produce the product. The only investigation conducted on the production of the product concerns packaging (CD 4.4). Packaging is also considered as a vital aspect of selling point, and thus, it is included in the investigation. The other production attributes, such as raw material (CD 4.1), tooling (CD 4.2), and production (CD 4.3), are considered insignificant as these attributes are more of the engineers’ concern rather than of industrial designers. The investigation of user needs on product life-cycle (CD 5) is also not investigated.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 2</td>
<td>MPD 2.1</td>
<td>ID 1</td>
<td>CD 1.1, CD 1.2, CD 1.3, CD 1.4, CD 1.5, CD 2.1, CD 2.2, CD 2.3, CD 3.1, CD 4.4</td>
<td>EM, CA, MG</td>
</tr>
</tbody>
</table>

*Table 5.9* – What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.1 – Identifying the needs.
In the context of industrial design measurements, industrial design emphasis (EM), capability (CA), and management (MG) play an important role in ensuring that the industrial design potential is implemented appropriately in this phase of the modular product design process.

**Analysis Approach (Code: MPD 2.2)**

There are several approaches to identify the needs of the customer. The needs information required are collected by surveying prospective customers. The first approach normally starts by conducting a market study to establish target markets and customers. Perhaps the most common method to identify the needs is through interviews, questionnaires, and by analysing competitive products to identify any possible improvement opportunities. Industrial Designers are trained in these tasks through specific industrial design approaches that emphasise on the two main concerns of aesthetics and usability. These concerns relate mainly to the psychological and physical needs of customers. In these matters, industrial design has a close relationship with the demand of customers, and in the process of industrial design, the demands play a very decisive role.

The involvement of industrial design in MPD 2 and MPD 2.2 is shown in Table 5.10. Basically, the potential of industrial design in MPD 2.2 is similar to MPD 2.1.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. measures</th>
</tr>
</thead>
</table>
| MPD 2     | MPD 2.2   | ID 1         | CD 1.1  
CD 1.2  
CD 1.3  
CD 1.4  
CD 1.5  
CD 2.1  
CD 2.2  
CD 2.3  
CD 3.1  
CD 4.4 | EM  
CA  
MG |

**Table 5.10** – What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.2 – Analysis approaches.

**Needs Grouping and Prioritisation (Code: MPD 2.3)**

Once the needs of the customers are identified, these needs are then grouped and prioritized according to their importance. There are several approaches used in the grouping
and prioritization exercise, but perhaps one interesting approach that could be adopted is the theory of Maslow’s hierarchy of needs (Kenrick, 2010; Cianci and Gambrel, 2003). In the perspective of this research, the needs of the customers are grouped and prioritized according to their psychological and physical changes, as well as their age group – from junior to senior basic needs. The theory also stated that specific needs of customers have many levels, which are gradual. In the industrial design context, this approach is significant as it determines the industrial design characteristics of a product according to the psychological and physical levels and the state of the customers. These groups and prioritised data are then analysed. The result of the analysis is a statement of recognized needs and the expected method in which the needs should be met.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 2</td>
<td>MPD 2.3</td>
<td>ID 1</td>
<td>CD 1.1, CD 1.2, CD 1.3, CD 1.4, CD 1.5, CD 2.1, CD 2.2, CD 2.3, CD 3.1, CD 4.4</td>
<td>EM, CA, MG</td>
</tr>
</tbody>
</table>

Table 5.11 – What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.3 – Needs grouping and prioritisation.

As shown in Table 5.11, the potential of industrial design in MPD 2.3 is similar to MPD 2.1.

Satisfying Customer Needs (Code: MPD 2.4)

The task of satisfying customer needs is probably the most vital, thus needing the most effort and commitment from the product development team. Once the needs have been recognized, they are then deployed as specific new features of an existing or new product. Many organisations aim towards exceeding customer needs and expectations of the product in order to compete in the highly demanding market environment. The response from customers to the product is integrated into a development effort to enhance the product, which will eventually further increase customer satisfaction towards the product. This is a
very significant step towards gaining customer loyalty. There are two (2) prominent approaches to investigate and identify customer satisfaction. They are: 1) Kano’s model of customer satisfaction (Kano et al., 1984) and 2) Quality function deployment model (Kovach et al., 2007). These models offer insights into the product attributes, which are perceived to be important to customers.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 2</td>
<td>MPD 2.4</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>CD 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td>CD 1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td>CD 2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td>CD 2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td>CD 4.4</td>
</tr>
</tbody>
</table>

Table 5.12 – What the application of industrial design in Phase 2 (MPD 2) of the modular product design process could look like; this table is for the task MPD 2.4 – Satisfying customer needs.

The main purpose of these models is to support the establishment of a product specification, as well as in facilitating discussion through better team understanding. Industrial design potential in this task is significant in satisfying customer needs through implementation of the appropriate industrial design critical dimension. The potentials of industrial design in MPD 2.4 are similar to MPD 2.3 (Refer to Table 5.12).

5.6.3 Product Requirement Analysis Standards

The product requirement analysis phase (Code: MPD 3) involves three (3) tasks. The tasks are:

1. Functional objectives (Code: MPD 3.1)
2. Operational and general functional requirements (Code: MPD 3.2)
3. Requirement importance assignment (Code: MPD 3.3)

These tasks are elaborated in the following paragraphs.
**Functional objectives (Code: MPD 3.1)**

In order to meet the customer’s primary needs, the development team needs to prepare a list of functional objectives. These objectives are a conception of the product function needed to satisfy customer needs, whereby these functions are the basic operations or transformations that must be carried out by a new product system to satisfy customer’s primary needs. For example, the primary need of a lap top computer bag is to carry the lap top computer. The need is so basic that it is not noticeable by the customer during a survey or interview (Refer to Table 5.13).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 3</td>
<td>MPD 3.1</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.2</td>
<td></td>
</tr>
</tbody>
</table>

*Table 5.13 – What the application of industrial design in Phase 3 (MPD 3) of the modular product design process could look like; this table is for the task MPD 3.1 – Functional objectives*

**Operational and general functional requirements (Code: MPD 3.2)**

Once the operational conditions and the physical limitations of the proposed product are identified during the needs analysis, the development team will translate the identified data into operational and general functional requirements. Operational functional requirements are a set of specific information that describes the constraints of a design in order to fulfil the intended function of the product. In this aspect, industrial designers must work together with other cross-functional team members to establish the lists. An example of operational functional requirement is the height constraint of a cup that should be about 10 centimetres. Meanwhile, general functional requirements are the criteria set by the design team to evaluate the resulting design to meet the customers’ secondary needs. These criteria are usually stated in general utility terms, such as ease of manufacture, ease of service and maintenance, as well as ease of operation and safety. Customers could eventually use these
criteria as critical technical differentiators that can further facilitate them in comparing competing products that carry out similar functions (Refer to Table 5.14).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 3</td>
<td>MPD 3.2</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.14 – What the application of industrial design in Phase 3 (MPD 3) of the modular product design process could look like; this table is for the task MPD 3.2 – Operational and general functional requirements.

Requirement importance assignment (Code: MPD 3.3)

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 3</td>
<td>MPD 3.2</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.15 – What the application of industrial design in Phase 3 (MPD 3) of the modular product design process could look like; this table is for the task MPD 3.3 – Requirement importance assignment.

The lists of the requirements (Operational functional and general functional requirements) should be weighted and assigned according to their importance. In a product,
there may be several requirements and their importance also varies. Therefore, the design team should not put a similar weight on different requirements. Different weights should be assigned to different requirements. The design team must also base their consideration of a requirement weight on the needs of the customer (Refer to Table 5.15).

5.6.4 System Decomposition Standards

The system decomposition phase (Code: MPD 4) involves three (3) tasks. They are:

1. *Generation of product/concept (Code: MPD 4.1)*
2. *Establishment of basic functional elements (Code: MPD 4.2)*
3. *Establishment of basic physical components (Code: MPD 4.3)*

These tasks are elaborated in the following paragraphs.

*Generation of product/concept (Code: MPD 4.1)*

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 4</td>
<td>MPD 4.1</td>
<td>ID 2</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 3</td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 4</td>
<td>CD 1.3</td>
<td>OC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td>MG</td>
</tr>
</tbody>
</table>

Table 5.16 – What the application of industrial design in Phase 4 (MPD 4) of the modular product design process could look like; this table is for the task MPD 4.1 – Generation of product/concept.

Once the tasks of the customer needs analysis are completed, and the design team has established the functional requirements of the product, the next phase in the modular design process is actually generating the product concept or design proposal. The generation of concepts or design proposal is the initial step where the manifestation of the product is seen. As with all product design processes, the manifestation begins with rough sketches based on the product design specifications that were established in phases two and three. The chosen sketches are further developed and finalized for prototyping. It is during this stage that the
decomposition of the product is conducted. The decomposition is divided into two elements; decomposition of basic physical elements, and decomposition of basic functional elements. The development of the product, as described earlier (Refer to Section 3.9.4), must adhere to the principles of modular product design (Refer to Table 5.16).

_Establishment of basic functional elements (Code: MPD 4.2)_

The basic functional elements are the elements that have been decomposed to represent the product or its parts intended behaviour (the functions). A function of a product can be executed by a single physical component (element) or by a combination of components that are configured in a specific order according to several logical considerations that will ensure the accomplishment of their intended combined function. Besides, the logical considerations define the mode of action that the product will perform.

Meanwhile, the decomposition of the components tasks involves the overall function of the component to be broken into sub-functions. These sub-functions are further decomposed into lower-level functions until a point where a set of functions that can be achieved by the available components is reached. There are two categories of functions; they include _primary functions_ and _auxiliary functions_. The primary functions support the overall functions in a direct manner, whereas the auxiliary functions support the overall functions in an indirect manner (Refer to Table 5.17).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 4</td>
<td>MPD 4.1</td>
<td>ID 2</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 3</td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 4</td>
<td>CD 1.3</td>
<td>OC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 5</td>
<td>CD 1.4</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 6</td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
</tbody>
</table>

_Table 5.17_ – What the application of industrial design in Phase 4 (MPD 4) of the modular product design process could look like; this table is for the task MPD 4.2 – Basic functional elements.
Establishment of basic physical components (Code: MPD 4.3)

In this task, the product is designed and decomposed into basic physical sub-components and/or sub-systems that are capable of accomplishing the product function. There are several major considerations that should be made during this task as the decomposed sub-components and sub-systems must adhere to the modular design principles. The decomposition design must allow the sub-components and/or sub-system to be separated easily. The separated sub-components and/or the sub-system must then be easily united or connected to other major/sub-components and/or major/sub-systems within the product range. These sub-components and/or sub-systems should also be adaptable to other major/sub-components and/or major/sub-systems outside the product range (Refer to Table 5.18).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 4</td>
<td>MPD 4.1</td>
<td>ID 2</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 3</td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 4</td>
<td>CD 1.3</td>
<td>OC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 5</td>
<td>CD 1.4</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 6</td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.18 – What the application of industrial design in Phase 4 (MPD 4) of the modular product design process could look like; this table is for the task MPD 4.3 – Basic physical components.

5.6.5 System Optimisation Standards

The system optimisation phase (Code: MPD 4) involves four (4) tasks. The tasks are:

1. System-level specification (MPD 5.1)
2. System-level specification impact on general functional requirements (MPD 5.2)
3. Similarity index and matrix (MPD 5.3)
4. Optimisation model and component grouping (MPD 5.4)

These tasks are elaborated in the following paragraphs.
**System-level specification (MPD 5.1)**

The output from the decomposition should enable the components to be arranged in modules and it can be integrated into a functional system. Moreover, the arrangement of the components in the modules will have a vital impact on the overall design of the product. The relationship between modules with respect to their functional and physical characteristics is defined as *system-level specifications*. This is generally the one-to-one relationship between components where the functional characteristics are a result of the transformation and operations that components perform in order to contribute to the overall performance of the product, while the physical characteristics are the result of the component configurations and assemblies that employ the function of the product (Refer to Table 5.19).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 5</td>
<td>MPD 5.1</td>
<td>ID 4</td>
<td>CD 1.1, CD 1.2, CD 1.3, CD 1.4, CD 1.5, CD 2.1, CD 3.1, CD 3.2, CD 4.1, CD 4.2, CD 4.3, CD 4.4, CD 5.1, CD 5.2</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 5</td>
<td></td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 6</td>
<td></td>
<td>OC</td>
</tr>
</tbody>
</table>

*Table 5.19* – What the application of industrial design in Phase 5 (MPD 5) of the modular product design process could look like; this table is for the task MPD 5.1 – System level specification.

**System-level specification impact on general functional requirements (MPD 5.2)**

It has been discovered that the general functional requirements are affected by the system-level specification. This is due to the fact that some specifications that are identified might prevent the application of some desired general functional requirements although many may help satisfy some. Therefore, the impact of the system-level specification on the general functional requirements must be clearly identified.
Table 5.20 – What the application of industrial design in Phase 5 (MPD 5) of the modular product design process could look like; this table is for the task MPD 5.2 – SLS impact on GFR.

The identification is vital as it helps in developing products that will meet the general functional requirements up to an appropriate level. However, if the system-level specification neither has impact on preventing implementation nor satisfying the general functional requirements, then the system-level specification is considered as ineffective (Refer to Table 5.20).

**Similarity index and matrix (MPD 5.3)**

Table 5.21 – What the application of industrial design in Phase 5 (MPD 5) of the modular product design process could look like; this table is for the task MPD 5.3 – Similarity index and matrix.

The degree of connection between the components or elements is measured before it is used to establish a component group to form a module (Refer to Table 5.21).
**Optimisation model and component grouping (MPD 5.4)**

In order to establish the modules as a working component or a complete product, the components need to be grouped (Refer to Table 5.22).

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 5</td>
<td>MPD 5.2</td>
<td>ID 5</td>
<td>CD 1.1, CD 1.2, CD 1.3, CD 1.4, CD 1.5, CD 2.1, CD 2.2, CD 3.1, CD 3.2, CD 4.1, CD 4.2, CD 4.3, CD 4.4, CD 5.1, CD 5.2</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 6</td>
<td></td>
<td>CA</td>
</tr>
</tbody>
</table>

Table 5.22 – What the application of industrial design in Phase 5 (MPD 5) of the modular product design process could look like; this table is for the task MPD 5.4 – Optimisation model and component grouping.

### 5.6.6 Synchronising of Processes

*Figure 5.5 – Potential application details: showing the synchronization of InDFM with a new product development process of a participating company.*
The potential application of InDFM in the conceptual modular design process is unrestricted as industrial design could be applied throughout all stages of the product design process. Application of InDFM in conceptual design process is easier as industrial design measures could be planned earlier before launching a project. For an existing or used modular design process, application of InDFM is more complicated as the process is already established. Thus, modification and adaptation to accept InDFM would be an intricate process. There will be a limitation on the implementation of InDFM, particularly in the phases where major engineering aspects dominate, such as specifying the system level and identification of similarity index phases. Figure 5.5 shows the potential application of InDFM at a conceptual modular product design process based on Section 5.7.

5.7 Application and Quality Assessment Priority

The priority levels for industrial design input and quality assessment act as the factors that determine the emphasis of industrial design in each phase of the modular product design process. The application of industrial design within these phases should be managed according to the set quality standard. The priority levels are described in the following section.

5.7.1 Industrial Design Input Priority Level

Priority level descriptions:

1. P1 (Highly significant)
   This is the highest priority level where industrial design must be applied in the specified phases of the modular development process in order to optimise its benefits. Failure to apply ID may result in no commercial success for the product or product range.

2. P2 (Significant)
   This is the second priority level where industrial design is recommended in the specified phases of the modular development process in order to optimise its benefits.
The application of ID may provide significant improvements that result in maximum commercial success.

3. **P3 (Applicable)**
   This is the third priority level where industrial design could be applied in specific phases of the modular development process in order to optimise its benefits. There may be hidden values that could benefit from the application of ID.

4. **P4 (Less applicable)**
   This is the fourth priority level where industrial design may provide some benefits if applied in the modular development process, but not necessarily needed.

### 5.7.2 Quality Control and Assurance Priority Level

Priority level descriptions:

1. **PQ1 (Highly required)**
   This is the highest priority level where the industrial design application and the industrial designers’ coordination with the project team members must be monitored and assessed constantly to maintain a high standard of output.

2. **PQ2 (Recommended)**
   This is the second highest priority level where the industrial design application and the Industrial Designers’ coordination with the project team members are observed, but not assessed.

3. **PQ3 (Not required)**
   This is the lowest priority level where the monitoring and assessment of industrial design application and the Industrial Designers’ coordination with the project team members are not required.

   It is imperative to address quality control and assurance resource requirements from the earliest stage of the project member formation. Furthermore, special attention must be
given to address these requirements in order to ensure a successful quality control and assurance assessment within each phase (Refer to Index 3).

### 5.7.3 Verification Checklist

<table>
<thead>
<tr>
<th>Development Phase</th>
<th>Checklist (Standard questions)</th>
<th>Yes</th>
<th>No</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each phase of modular product design</td>
<td>Are you currently applying ID in this phase of your product development process? In which activity is ID applied?</td>
<td>(Check)</td>
<td>(Check)</td>
<td>Justifications on why industrial design is applied / not applied in this phase; and description of actual activity where industrial design is applied.</td>
</tr>
<tr>
<td>Activity &amp; code: E.g. Classification of modular product development project (MPD1.1)</td>
<td>Do you think ID is relevant in this phase of your product development phase? In which activity is ID relevant?</td>
<td>(Check)</td>
<td>(Check)</td>
<td>Justification on the relevance of industrial design in this phase; and the activity where industrial design is relevant.</td>
</tr>
<tr>
<td></td>
<td>Are you planning to apply ID in this phase or some activities of this phase?</td>
<td>(Check)</td>
<td>(Check)</td>
<td>Justification on the industrial design application decision.</td>
</tr>
<tr>
<td>What is your general ID priority in this phase?</td>
<td>Suggestion; recommendation; and justification of the industrial design priority, based on ID priority level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final decision:</td>
<td>Confirmation of final decisions whether to apply / not to apply industrial design within this phase.</td>
<td></td>
<td></td>
<td>Justification of the confirmation of decision.</td>
</tr>
</tbody>
</table>

Table 5.23 – An example of verification checklist of industrial design application within each phase of the modular product design process (E.g.: Phase 1 – Product planning); this checklist may be used with other activities in this phase.

This checklist table (Refer to Table 5.23 and Index 3) is used to verify the relevance of industrial design within each activity of the modular product design phases. The objectives of the checklists are listed in the following:

1. To determine the potential of industrial design application in each development phase.
2. To identify the activities where industrial design is applied.
3. To justify the relevance of industrial design application within each development phase.
4. To endorse decision to apply industrial design within each development phase.
5. To establish the general industrial design priority within each development phase.

The justification results could be used to determine the final decision of considering the feasibility of industrial design in each phase within the modular product development process the company is using.
Chapter 6

6. Implementation Outcome Analysis

Objectives: This chapter investigates the feasibility of an industrial design methodology through the implementation of InDFM developed in chapters 4 and 5. The methodology is then evaluated and validated. The key aims of this chapter are:

- To analyse the implementation of InDFM
- To evaluate and validate the efficacy of the InDFM methodology

6.1 Outcome Analysis

The implementation analysis of the framework is conducted with a fully developed InDFM. The InDFM is presented to companies that participated in the research to assess and validate the feasibility of the framework on their modular product design and development processes. Significant feedback from the participating companies had been recorded. The purpose of the InDFM implementation process was to determine if the developed framework met the required and relevant industry requirements. The implementation of the InDFM was evaluated and validated through the use of specified measurement procedures. The outcomes of these exercises should indicate the level of feasibility of the InDFM methodology and the quality of accomplishment of its intended application. The quality of accomplishment refers to an assessment of the quality of the PDP according to *QC and QA Priority Level* (Refer to Index 3, Page 254).

6.1.1 Analysis Context

The analysis of the InDFM was conducted by using the existing modular product design process of a participating company. The InDFM Standards were retrospectively implemented to the existing process to determine the adaptability of the framework to the applied process. The participating company was involved directly in research, design, and
development of both modular and non-modular products. The InDFM was implemented on the design and development service company that was selected, based on the company’s portfolios of designing and developing modular products for several major product companies, which were both original equipment manufacturers (OEM) and sub-contractors. Several evaluation criteria were determined before the evaluation exercise was conducted. Validation feedback documents were prepared, which were to be completed with critical information by the product development manager or any relevant personnel assigned to validate the feasibility of the framework. The comments and feedback were based on the product development manager’s or relevant personnel’s qualitative judgments of the framework. The completed evaluation and validation documents were recorded and analysed.

6.1.2 Evaluation Criteria

This section discusses the development of evaluation criteria for use in feasibility valuation process. It had been important that the evaluation criteria met the following aspects:

- Reflects the companies’ needs and facilitates the preparation of improvements that best satisfy those needs.

- Provides for an accurate evaluation of the framework.

- Represents key areas of importance and emphasises to be considered in the evaluation decision.

- Supports meaningful discrimination and comparison between the InDFM and the existing development process.

6.1.3 Determining Evaluation Criteria

Evaluation criteria were used directly to measure progress towards objectives of the framework application. The evaluation criteria used to assess the framework consisted of the factors and the sub-factors that reflected the areas of importance of the participating companies’ process. Through the evaluation factors, the companies would be able to assess
the similarities and the differences, as well as the strengths and the weaknesses of the framework in comparison to their existing process and use that assessment in making decisions about accepting the implementation of the framework into their processes. A well-integrated evaluation scheme provides consistency, discipline, and rationality to the decision process.

For the purpose of this research, the following evaluation criteria were determined based on the specifications set for the development of the framework. The criteria include:

1. The applicability of the InDFM as an industrial design optimisation tool for the new or existing modular product design process.
2. The applicability of the InDFM as an industrial design management tool for the new or existing modular product design process.
3. The potential of InDFM as an enhancement tool for the modular product design process.
4. The capability of InDFM in supporting the collection of industrial design requirement data.

An example of the evaluation form can be found in Index 3 on Page 272.

6.2 Evaluation Exercise – FN Herstal

The evaluation exercises were conducted with a participating company – FN Herstal, as a single case study company. This company was selected based on their products and services that involved modularity. The following are the justifications for the selection of a single case study company.

1. Product focus – The researcher’s decision to focus this research on defence product, which was the assault rifles system, and that narrowed the selection of company to only a few.

2. Research response – Only three (3) out of the fifteen (15) participating companies responded to the survey were defence product producers, but only one (1) was interested in the research collaboration.
3. **Design and innovation capability** – The selected company was considered to possess a highly competent design and innovation capability based on the number of product variation available in their portfolio. An example of the company’s innovative design approach to the assault rifle is the production of an unconventional *Bullpup* layout (Refer to Figure 6.3), which is not only ergonomic, but depicts styling value that is absent from most conventional rifle design. This shows that the company had been willing to embark into unfamiliar area in assault rifle design by applying industrial design albeit not realising they had done it.

4. **Modular product approach** – New products and weapon systems have adopted an open architecture in order to support modular product design. Hence, this company employed a significant approach to facilitate rapid specifications improvements or changes according to the requirements of different users not only in the aspect of technology, but also physically.

The participating company evaluated the InDFM based on the criteria provided in the evaluation forms (Refer to Index 3, Page 251, 271). The following sections describe the evaluation outcomes conducted with the participating company.

### 6.2.1 Company’s Background

FN Herstal is part of Herstal Group of companies. FN is a product organisation that is known for its comprehensive range of firearm products, ranging from small and less lethal side arms to highly sophisticated aircraft mounted weapon systems. In fact, *Browning®* (Refer to Figure 6.1) and *Winchester®* rifles are acquired by the Herstal Group; making them one of the largest manufacturers and developers of a comprehensive range of firearms and associated accessories used in defence, law enforcement, and games hunting.

![Figure 6.1 – The X-Bolt, an example of the latest model of game hunting rifle made by Browning (Source: Browning.com, 2014)](image-url)
The headquarters of the Herstal group is located in Herstal, an industrial city in the South-East of Brussels in Belgium. This company also has offices in several other European countries, North America, and Asia. FN Herstal business is claimed to focus on innovation and product improvement. This has resulted in the development and production of a comprehensive range of highly sophisticated weapons systems, and associated products being used by the Military and Law Enforcement operators around the world.

6.2.2 Modular Product Experience

FN Herstal has developed and produced both integral and modular weapon systems. One of the highly modular weapon systems developed is the *FN SCAR* (Special Command Assault Rifle) weapon system (Refer to Figure 6.2), which consists of two highly adaptable modular rifle platforms and a grenade launcher. The weapons come in three different sizes of barrel designed for conducting specialised operations, such as battle in close range (*or close-quarters battle/combat*), standard infantry, and longer-range precision fire roles. All the barrels can be easily and quickly interchanged by the operator to quickly adapt the requirements of different mission applications.

![Figure 6.2 - FN SCAR modular assault rifle variants (Source: FN Herstal, 2010)](image-url)
Additional accessory component of the rifle, such as ‘Enhanced Grenade Launcher Module’ (EGLM), is easily and quickly mounted under the barrel of any SCAR platform, providing additional capability to individual firepower. This module can also be easily configured for use as a stand-alone weapon. From the SCAR system’s modular design, as well as ergonomic commonality and parts commonality, the weapon system represents significant advantages in the minimisation of training costs and life-cycle support.

In addition to the traditional lethal weapon system, this company has designed and developed less lethal weapon systems, which also allow adaptability through modular platform and parts commonality. The less lethal weapon system provides alternatives to military and law enforcement users to neutralise suspects with minimum risk. This weapon system currently comes in two configurations, which include rifle-size and holster-size projectile launchers.

In addition, the most new products and weapon systems produced by the company have adopted an open architecture design approach to support future advancements in operational requirements, which include ammunition, aiming devices, sighting systems, and other equipment, that are critical to a mission.

6.2.3 Fundamental Investigation

A visit was made to FN Herstal for an investigation interview and to give a presentation on the proposal to apply InDFM to the company’s design and development process. The request for the visit was accepted as the company was interested to know further about the proposed framework research. The company anticipated that the presentation might relate to what they were doing and how industrial design, as well as modularity, might be envisaged to work within the company’s product design and development process. As described in the previous sections, three (3) categories of primary investigations were conducted (Refer to Chapter 4, Section 4.2.1.1) with this company.

Several interviews and surveys were conducted with the research and development personnel to investigate and identify elements of industrial design and modularity within their existing product design process. The investigation was recorded and analysed. The outcome of the investigation provided highly relevant information about the actual design process used
by the company and how industrial design could influence the overall design scenario of each product developed through the applied process. Besides, the scope of the investigation was centred on the design and the development of products within the category of personal weapons, including rifles and side arms, with industrial design and design for modularity as the key factors that influenced the discussion. The products, however, were not limited to conventional firearms, but they also included less lethal weapons since the company was then actively developing a less lethal weapon system.

6.2.3.1 Company’s Potential Industrial Design Needs

Based on the data gathered by the researcher during the investigation, in the current context, the company has been consistently aiming to develop highly sophisticated weapon system configurations instead of traditional firearm applications, thus resulting in solutions dedicated to integral design rather than modular design. This design approach has led to a lot of design variants, which were very complicated to manage. This type of design solution typically linked subsystems with closely coordinated interaction and distinctive features that could not be easily connected to other systems due to complex and non-standard interfaces. Therefore, producing product varieties requires numerous design changes and product re-design. However, the design and development (R&D) department has to continue with the existing process in order to meet the clients’ variant requirements, for example – *the request for different kinds of optics for a specific rifle*. This situation has made the company highly occupied with a lot of variants for different kinds of requirement from both military and security clienteles. Despite this, the company was able to meet all the requests albeit experiencing numerous complications as they were consistently improving their design and manufacturing processes, particularly in terms of the efficiency of manpower and new technology application. Moreover, new Research and Development staffs were consistently trained in the aspects of design optimisation with the use of the latest digital modelling software without affecting the original design configuration. The design optimisation in this context generally emphasised components design improvement in order to meet the user’s needs for functional and physical varieties. To some extent, these activities failed to deliver a systematic approach and were immensely done in an ad hoc manner based on experience. As such, industrial design was neither applied in managing nor supported the design process. In actual fact, industrial design was not considered as one of the priorities in the company’s
strategic product planning (Refer to Chapter 4, Section 4.3.1.1), therefore, there was no emphasis on applying industrial design in the product design process.

In that notion, however, the company did not conduct any functional analysis for their products and the concept of the company’s products had been very fixed. For example, if the design department was given a project to develop a new rifle, the teams involved would already have comprehensive knowledge on rifle components and their functionalities. Therefore, functional analysis was completely ignored and the focus would be placed on the physical characteristics of the product since functionality is already in the background. This situation could be a disadvantage because the company would lack in innovativeness if they continue with this kind of reasoning. This would not benefit the company since it is believed that innovation can be related to new functionalities, and provide new ways to work, as well as articulate the functionalities. This is an aspect that the design manager could try to introduce into the company since the current design teams were always thinking in terms of solutions instead of the problems to be solved. This is one of the main issues that made application of the modularity concept very difficult since the design teams were thinking in terms of solutions instead of functions, whereby the integration of both solutions and functions should provide better outcomes. The existing design and development process of the company had been used extensively and changing the current company’s management approach to an innovative product design and development approaches proved to be complicated.

Figure 6.3 – FN F2000 assault rifle (top) and FN P90 sub-machine gun (bottom). Both products have elements of industrial design and product commonality in the body design (Image Source: world.gun.ru, 2012)
Innovation is one aspect the company claimed to have as one can observe from the designs created by the company in F2000 assault rifle and the P90 sub-machine gun (Refer to Figure 6.3). The outlook of the weapons carried by the military personnel should give a sense of security to the public yet pose a significant intimidation to any potential security offenders or terrorists (Refer to Figure 6.4). During the investigation, the researcher was given the opportunity to handle one of the products (F2000) and it was indeed quite impressive with the ‘feel’ from the ergonomic, material, and styling point of view. It was rather eccentric that the researcher used the term *styling* for a lethal product, but as the perceptual determinants of a product style may be thought of at several levels, this particular product provides a visual impression that the operators of the weapon are not only affable, but formidable at the same time. Industrial design elements can also be seen in the design of the product, although no formal industrial design process was conducted during the design and development of the product. Industrial design application in the product design phase is highly significant (Refer also to Chapter 4, Section 4.3.1.2) and many organisations are beginning to realise the importance of industrial design within this phase, including FN. Implementing industrial design can bring about a new emphasis on the company’s design activities, such as the enhancement of styling and aesthetics aspects, as well as the product users’ interactions and ergonomics factors in operating the product. Industrial design is also crucial in determining component interfaces interaction and enhancement of utilities aspects of the products.

*Figure 6.4 – Armed French soldiers patrol Gare du Nord station in Paris with a FAMAS rifle; a similar ‘Bullpup’ design rifle as the F2000 (Photo source: Getty Images-AFP, 2010).*
Unfortunately, the products were not well received, thus limiting the product to a very small market. The F2000 assault rifle is not the preferred weapon of choice for most NATO countries. Slovenia is the only NATO member country that uses F2000 as standard issue rifle for their armed forces, while other operators of the rifle are mainly Special Forces group. Most of the company’s customers prefer to purchase conventional designed firearm. This situation has indicated that the industrial design elements were not appropriately implemented, thus resulting in weak industrial design values.

![Image of a rifle](Image source: FN Herstal, 2010)

**Figure 6.5** – *FN 303*- a rifle size of less lethal weapon system components made by FN currently in the market (Image source: FN Herstal, 2010)

To continue the innovative approach, the company was then researching the potential for other emerging markets, such as the less lethal application (Refer to Figure 6.5). This is a new category of weapons that minimise the risk of serious injury or even fatality. The marketing department of the company described the design of the less lethal weapons as extremely bulky, thus termed it as the ‘*old-style Russian thing*’. Suggestion was given that the design department should develop a kind of distinctive design that would directly point out all the facts that the rifle is less lethal. The suggestion is a difficult task to be met by the design department as the design of the product is relatively linked to the technology and the way the product is used. During the investigation, the design manager stated that in contrary, the design of a weapon needs to look threatening. The design department was facing difficulties in designing the less lethal weapon as it must be seen as threatening (to scare) and less threatening simultaneously because it reflects a less lethal effect. Realising the difficulties, the design department had identified that this issue required functional analysis and industrial design, particularly in the aspects of product communication and utility.
On investigating the aspect of utility, the researcher found out that it had a very close relationship with product interaction, that is, between the product and its user. This is one aspect that should be pointed out as utility is not just performance, but also the interaction between the user and the product in terms of operation, maintenance, and material. Besides, utility should be considered throughout the design process without affecting or compromising the performance aspects of the product. In fact, considering utility in the design process could enhance the overall performance of the product. However, putting too many design considerations, such as utility, for example, within the existing product design process further complicates the overall design process. This view, at present, is not favoured by the marketing department as the company has been embarking and focusing on a very large program of new product design and development. The management and product development department are very careful, thus the concept of modularity is difficult to achieve in the environment as it was then not considered a priority.

Nonetheless, only a small number of the company’s products depends on a modular platform. These being the FN SCAR, F2000, and the less lethal weapon systems within the category of personal weapon, thus vehicle mounted weapons systems were excluded in this research. A modularity concept should be clarified by pointing out that there are different kinds of modularity. The introduction of modularity concepts may lead to putting additional requirements into the product specification without compromising its performance. For the company, performance has always been the priority, while modularity is something in the background. The technology of the company’s product is so mature that it is difficult to increase the performance further, and therefore, a differentiator was looked into. The design department should look into different areas to improve and the two major points that could be improved, in fact, had been industrial design and modularity. With that, the company has been trying to redefine a new product development framework, where industrial design and modularity could be included as part of the major attributes within the new framework as they are quite adaptive and flexible. Their inclusion could improve the value of the whole process.

With regard to industrial design, the visual appearance for military product is less vital compared to the consumer market as the military market would be more interested in utility rather than appearance. Generally, in military equipment acquisition, appearance is not really an important criterion that buyers are putting into their requirements. In relation to this,
the researcher earlier pointed out that industrial design has several specific goals and appearance is just one of them. For military products, such as the assault rifle, the industrial design consideration that is most appropriate would be within the aspects of ergonomics, utility, choice of material, and cost. These are the most significant differentiator factors that are needed to put the company on an advantageous position than their competitors.

6.2.3.2 Stimulation of Industrial Design and Modularity

Based on the investigation on the design and development approach of this company, the researcher underlined several factors that stimulated the major needs for industrial design. These needs could be addressed through the integration of industrial design and modularity concept within the process employed by the company. The needs were observed in two vital activities encompassing design and management, of the investigated company. The following are factors that prompted the industrial design needs.

**Design**
1. *Integral design* – The company has been constantly developing highly sophisticated and specialised weapon system configurations resulting in integral design solutions.

2. *Functional analysis* – had never been conducted in the product design and development process.

3. *Model variant* – There were too many model variants leading to managing complexity.

4. *Product value* – There was lack of distinctive values in the existing product range.

5. *Product development process* – had been too focused on solutions instead of functions with no integration of both solutions and functions.

6. *Innovation restriction* – There has been a restricted approach to innovative design as the design of products is closely linked to the technology and manufacturing factors.

**Management**
1. *Contentment* – the existing design and development process restricts innovative design and development approach.
2. *Customer preference* – Unconventional product design configuration is not well accepted by customers.

3. *Second choice* – The concept of industrial design and modularity were not considered a priority in the process.

4. *Fixed mind set* – Difficulty in changing the mind set of the top management and marketing department to realise the need for a new design and development approach.

### 6.3 InDFM Implementation Process

As mentioned in Section 4.2, any large product development project process duration could take a minimum of two years to be completed. During the investigation on the process used by the design department of FN, the researcher found that the process was ‘extensive and complicated’. Therefore, to facilitate the research, the researcher proposed an investigation approach (Refer to Figure 6.6) about how the researcher could be involved in the investigation and implementation of InDMF in the design and development process of the company. The investigation approach was basically a schedule plan of how and when the researcher was going to be involved throughout the analysis period. The application of the investigation approach required the researcher to collaborate with the design engineer in each stage of the process to facilitate efficient integration of the InDFM within the process that was employed.

![Figure 6.6 – InDFM implementation process outline](image)

160
The following are the elaboration of the research investigation and the involvement plan in implementing the framework process.

**InDFM** – The InDFM was introduced in detail to the design department’s design managers and engineers. The introduction task was crucial to get the design managers and engineers to fully understand the concept of InDFM before they could apply it within the project phase.

**New PDP** – The first step in applying InDFM in new product development process (PDP) was by fully integrating InDFM within the new PDP. This was done by convincing the product development managers about how InDFM could be useful to enhance the total PDP. The integration of InDFM in the new PDP was comparatively a simple task as the PDP was not applied.

**Current PDP** – The InDFM needed to be retrospectively integrated into the current PDP. The researcher collaborated with the design engineer to identify the appropriate stages of the current process where industrial design and modularity aspects could be applied.

**Integrated PDP** – Each identified stage was comprehensively analysed to verify the appropriate industrial design and modularity aspect. The analysis was a significant step to ensure that the newly introduced aspects did not compromise product specifications. An analysis was also conducted to determine the inferences between the new PDP (with InDFM) and the then PDP (with InDFM).

**Outcome** – The outcomes from the application of InDFM into the new and the employed PDP were recorded and analysed. The results of the analysis were then used as a reference for further improvement and development of InDFM. The physical outcome from the implementation was evaluated through a standard evaluation form (Refer to Index 3, Page 274).

**Validate** – The feasibility of InDFM was validated with the product design and development manager. The validation task encompassed all the stages involved in the PDP. The validation task involved qualitative analysis of the evaluation outcome (through the standard evaluation form), in which the outcome of the analysis were then endorsed by the design and development manager for approval or rejection.
6.3.1 Implementation Investigation

The duration needed for the InDFM implementation investigation was scheduled for six months with an additional two months for contingency. Since the company had no new project to facilitate the investigation from an initial project definition stage, the researcher was advised to schedule the investigation based on the ongoing projects by retrospectively applying the InDFM within the company’s existing process.

The company was working on the SCAR and the less lethal weapon system project at the time of the research, and the SCAR project was at the final design refinement stage. For the less lethal weapon system, basically, the project was divided into two categories, which were the rifle size less lethal weapon system and bolster size less lethal weapon system. The rifle size weapon system initial concept was based on an integral architecture, whereby the system itself was not modular and any variants needed the system to be extensively modified to meet a required specification. However, the researcher noticed the possibility to transform part of the process to create modular variants and the design department was interested to see how this could be done via InDFM. The development for the rifle size less lethal weapon system was completed and the initial batches of production had been introduced into the market. Meanwhile, the bolster size less lethal weapon system was modular and was still at the initial stage of the development, thus making it the best platform for the research investigation for implementing the InDFM, together with the rifles from the SCAR project. A discussion was carried out with the design and development manager to identify the area for possible industrial design and modularisation on both system categories. Following this, the researcher decided to investigate the implementation of InDFM on the SCAR rifle.

6.3.2 Implementation – Process Adjustment

This chapter investigates the implementation of InDFM in an existing modular design process of FN. The original PDP (Refer to Index 4) was acquired from the company. The process was analysed to identify possible adjustment to facilitate adaptation with InDFM. Generally, for a newly developed process, the adjustment would not be vital as InDFM could be integrated within the process during the process development. For this research
investigation however, the researcher had to adjust some stages of the given process (Refer to Figure 6.7) by combining several tasks from the original concept in the feasibility stage.

**Figure 6.7 – An overview of a PDP of FN adjusted for application of InDFM – Refer to Index 4 for reference of the original proposal.**

Based on the suggestion by the project manager, the researcher decided to apply the framework retrospectively on the **SCAR** system (Refer to Figure 6.8) and set about investigating the workability and concurrently evaluate the outcome. The outcome was then self-validated based on feedbacks from the design staff members involved. The acronym of the **SCAR** weapon system is **SWS**.

**Product:** **SCAR Weapon System (SWS)**

**Figure 6.8 –** The standard design of the SCAR MK16 rifle designed and produced by FN; which was used for investigation of InDFM implementation.
**Product Definition – MPD1**

The researcher identified some minimal industrial design aspects involved in this phase of the SWS design process. The researcher identified that there could not be any industrial design process in this phase, except for measures consideration, where industrial design emphasis (EM) was discussed and determined by the project management team (Refer to Table 6.1). As mentioned in Section 5.3.1, industrial design emphasis was connected with a company’s strategic planning, whereby the decision to include an industrial design in their product design activities had been discussed, as well as the degree to which industrial design was put under consideration within the SWS project. Industrial design EM was applied in this phase, as suggested by the project manager as the launching platform for implementation of InDFM into the existing process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 1</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>EM</td>
</tr>
</tbody>
</table>

*Table 6.1 – Application of industrial design in MPD 1 – Modular product definition of the existing modular product design process of SWS.*

**Evaluation:**

The decision was evaluated and all staff members involved agreed that industrial design processes should be considered in the next phase of the process.

**Needs Analysis – MPD2**

The *needs analysis* phase (Code: MPD 2) involved four (4) tasks. The tasks were:

1. Investigation of needs (Code: MPD 2.1)
2. Analysis approach (Code: MPD 2.2)
3. Needs grouping and prioritisation (Code: MPD 2.3)
4. Satisfying customer needs (Code: MPD 2.4)
Investigation of Needs – MPD 2.1

The second phase (MPD 2) of the SWS product design process involved the investigation into the new needs of users. The design team’s first task was to identify what the actual needs and the new needs were. Data from the investigation were used to describe the product fully in terms of new added functional needs and physical limitations. These factors were used to form the new product design specifications. Industrial designer involvement in this task was to source information from potential customers and other sources, such as the customer, for which the product was being made, the competitor, and the relevant authorities that could impose restrictions on the product. The industrial design task in this phase had been an investigation into the customer’s needs (ID 1). In the context of SWS, the industrial design user needs were categorised into two main concerns – *usability* (functionality) and *how it looks* (visual appeal). In term of usability, the added function for the SWS was the ability to change internal and external components for different climate and environment use. In terms of visual perception, the SWS should be able to camouflage to different operational colours, such as snow, desert, savannah, and jungle. These two aspects were viewed as the key outcomes of industrial design, which were only attainable through consideration of the industrial design critical dimension. As observed from Table 6.2, the investigation of product usability (CD 1) involved all the usability attributes. The investigation of product aesthetics (CD 2) also involved all the visual attributes. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played important roles in ensuring that the industrial design potential had been implemented appropriately in this phase of the modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 2</td>
<td>MPD 2.1</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.2 – Application of industrial design in Phase 2 (MPD 2) of the modular product design process of SWS; this table is for the task MPD 2.
Evaluation:

The SWS design was based on a matured product platform. The company is renowned for producing reliable assault rifles for decades and it is natural that the SWS design is based on a successful conventional design, such as the M16. However, the implementation of InDFM could not be conducted throughout the process and the only way to innovate the design was through minimal changes of feasibility and visual aspects. The design staff members involved agreed that new needs of the customer should be examined. Apart from conducting new surveys and revisiting customers’ purchasing records, the design staff members were encouraged to generate new innovative ideas for user improvement – product interactions through design and usage of new materials to create an enhanced handling and feel for the rifle. This move provided for the possible customisation choices of any potential customer.

Analysis Approach – MPD 2.2

The needs information required was collected by surveying the existing and new potential customers. The first approach normally starts by conducting a market study to establish markets and new customers for the SWS. The most common method to identify the needs is through interviews, questionnaires, and by analysing competitive products to identify any possible improvement opportunity. In the context of SWS, the concerns of visual and usability aspects are related mainly to the operational and physical needs of customers. In these matters, industrial design has a close relationship with the demands of the customer, and in the process of industrial design, the demands play a very decisive role. The involvement of industrial design in MPD 2.2 is shown in Table 6.3. Basically, the potential of industrial design in MPD 2.2 is similar to MPD 2.1. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played an important role in ensuring that the industrial design potential was implemented appropriately in this phase of the modular product design process.
Table 6.3 – Application of industrial design in Phase 2 (MPD 2) of the modular product design process of SWS; this table is for the task MPD 2.2

Evaluation:

The evaluation outcome had been similar to MPD 2.1.

Needs Grouping and Prioritisation (Code: MPD 2.3)

From the perspective of the SWS research, the needs of the customers were grouped and prioritized based on their operational and physical changes. In the industrial design context, this approach had been significant as it determined the industrial design characteristics of the SWS product based on the operational and physical states of the system. These grouped and prioritised data were then analysed. The result of the analysis was a statement of recognized needs and the expected method in which the needs should be met. As shown in Table 6.4, the potential of industrial design in MPD 2.3 had been similar to MPD 2.1 and 2.2. Besides, in the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played important roles in ensuring that the industrial design potential was implemented appropriately in this phase of the modular product design process.

Table 6.4 – Application of industrial design in Phase 2 (MPD 2) of the modular product design process of SWS; this table is for the task MPD 2.3
Evaluation:

The evaluation outcome had been similar to MPD 2.2.

Satisfying Customer Needs (Code: MPD 2.4)

The task of satisfying customer needs is probably the most vital, thus needing the most effort and commitment from the product development team. In the context of SWS, once the needs had been recognized, they were then deployed as new added features of the SWS. The customer satisfaction on new added functional needs—*usability* (functionality) and *how it looks* (visual appeal) was investigated. Industrial design potential in this task is significant in satisfying the customer needs through the implementation of the appropriate industrial design critical dimension. The involvement of industrial design in MPD 2.2 is shown in Table 6.5. Basically, the potential of industrial design in MPD 2.4 had been similar to MPDs 2.1, 2.2, and 2.3. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played important roles in ensuring that the industrial design potential was implemented appropriately in this phase of the modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 2</td>
<td>MPD 2.4</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td>MG</td>
</tr>
</tbody>
</table>

Table 6.5 – Application of industrial design in Phase 2 (MPD 2) of the modular product design process of SWS; this table is for the task MPD 2.4

Evaluation:

The evaluation outcome had been similar to MPD 2.3.
**Product Requirement Analysis – MPD 3**

The *product requirement* analysis phase (Code: MPD 3) involved three (3) tasks. They were:

1. **Functional objectives (Code: MPD 3.1)**
2. **Operational and general functional requirements (Code: MPD 3.2)**
3. **Requirement importance assignment (Code: MPD 3.3)**

**Functional objectives (Code: MPD 3.1)**

In order to investigate the customer’s primary needs, the development team needs to prepare a list of functional objectives. These objectives are a conception of the product function needed to satisfy customer needs, whereby these functions are the basic operations or transformations that must be carried out by a new product system to satisfy customer’s primary needs. In the context of SWS, the primary need of the SCAR weapon system was for offensive and defensive military operations. The need is so basic that it is not noticeable by the customer during a survey. The investigation of MPD 3.1 required industrial design involvement that included all attributes of CD1, CD2.1, and 2.3. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played important roles in ensuring the industrial design potentials were implemented appropriately in this phase of the modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 3</td>
<td>MPD 3.1</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
</tbody>
</table>

*Table 6.6 – Application of industrial design in Phase 3 (MPD 3) of the modular product design process for SWS; this table is for the task MPD 3.1*

**Evaluation:**

The primary need of the SWS had been identified and confirmed. The SWS design was based on a mature product platform and there was no other known primary need for the
SWS. Discussions with focus group were conducted to identify new primary needs for the SWS and several potential primary needs had been proposed. The SWS was initially designed as a special operations weapon and such operation does not always involve engagements or fire fights. Thus, the SWS could be used as a deterrent factor to any possible aggressors. The SWS could also be used as a civilian protection element that could provide a sense of security for those under protection. Nonetheless, the design staff members involved agreed that the new primary needs of the customer should be examined further. Apart from conducting new surveys and revisiting customers purchasing records, the design staffs were encouraged to generate new innovative ideas for the improvement of visual aspects of the SWS through design and usage of new colour materials to create enhanced visual perspectives for the rifle. This move also provided possible customisation choices.

Operational and general functional requirements (Code: MPD 3.2)

Operational functional requirements are a specific set of information that describes the constraints of a design in order to fulfil the intended function of a product. In the context of SWS, the Industrial Designers must work together with other cross-functional team members to establish the lists. One aspect of operational functional requirement for SWS was that the SCAR rifle must incorporate rails for attachment of support components, such as sight or laser optics, and a grenade launcher. On the other hand, general functional requirements are the criteria set by the design team to evaluate the resulting design to meet the customers’ secondary needs. These criteria are usually stated in general utility terms, such as ease of manufacture, service and maintenance, as well as operation and safety. Customers could eventually use these criteria as critical differentiators to facilitate them in comparing competing products that carry out similar functions. The industrial design involvement in MPD 3.2 included all the attributes of CD1, CD2.1, 2.3, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played important roles in ensuring that the industrial design potentials were implemented appropriately in this phase of modular product design process.
Evaluation:

The specific operational functional requirements of the SWS were based on the specific requirements placed by the customers. As the SWS design was very reconfigurable, the basic design of the SWS could be configured to meet several other operational functional requirements, such as sniper support rifle (SSR), close quarter combat (CQC variant with short barrel), launching of grenade (with grenade launcher attached to rifle body), and shooting of bigger size calibre (or bullet) for better amour penetration. Discussions with the focus group within the cross-functional project team were conducted to identify new or additional operational functional requirements for the SWS. The design staff involved also agreed that new or additional operational functional requirements should be within the reconfigurable limits of the SWS. They were also encouraged to generate new innovative ideas for improvement of the operational functional requirement aspects of the SWS through integration of accessories components, such as for launching of emergency or search flairs, as well as telescopic and night vision optical capabilities. The SWS, being easily reconfigurable, provides comprehensive and significant customisation possibilities for specific customers’ requirement.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 3</td>
<td>MPD 3.2</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.2</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.7 – Application of industrial design in Phase 3 (MPD 3) of the modular product design process of SWS; this table is for the task MPD 3.2
**Requirement importance assignment (Code: MPD 3.3)**

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 3</td>
<td>MPD 3.2</td>
<td>ID 1</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td>ME</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.2</td>
<td></td>
</tr>
</tbody>
</table>

*Table 6.8 – Application of industrial design in Phase 3 (MPD 3) of the modular product design process of SWS; this table is for the task MPD 3.3.*

The lists of the requirements (Operational functional and general functional requirements) should be weighted and assigned based on their importance. In the context of SWS, there may be several requirements and their importance is also varied. Therefore, the design team should not place similar weight on different requirements. Different weights should be assigned to different requirements. The design team must also base their consideration of requirement weights on the needs of the customers. The industrial design involvement in the investigation of MPD3.3 included ID1, as well as all attributes of CD1, CD2.1, 2.3, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), and management (MG) played important roles in ensuring the industrial design potential was implemented appropriately in this phase of the modular product design process.

*Evaluation:*

The design team generally prioritised and weighted the operational functional requirements according to the customers’ needs for specific components and accessories, as well as the quantity of product ordered. Specific product procurement, such as the SWS for example, was given high priority as the new rifle was intended to rectify the shortcomings of the older rifle model, such as the M-4 (Refer to Figure 6.9). The improvement of firepower was the vital operational functional requirement of the SWS, as much as the usage of the rifle in urban or built-up settings. The improvement of shooting velocity beyond the capability of
the older M-4 was also placed as another vital priority. But above all, fulfilling a specific special operations forces requirement for an easily modifiable rifle to be used for both urban combat and for extended-distance shooting had been the utmost priority for the SWS design team. To meet this specific requirement, the design team designed a unique modular rifle system to accommodate various bullet rounds sizes (light 5.56mm and heavier 7.62mm rounds), as well as the ability to accommodate both short and long barrels lengths. The modular rifle system also allowed major components to be easily interchangeable between the variants models. This allowed operators to quickly replace their barrels to deal with a changing tactical situation.

![Figure 6.9 – A standard M-4 assault rifle is an upgraded derivative of the M16, commonly used by military operators since the 1960s (Source: world.gun.ru, 2014)](image)

**System Decomposition – MPD 4**

The system decomposition phase (Code: MPD 4) involved three (3) tasks. The tasks were:

1. *Generation of product/concept (Code: MPD 4.1)*
2. *Establishment of basic functional elements (Code: MPD 4.2)*
3. *Establishment of basic physical components (Code: MPD 4.3)*

**Generation of product/concept (Code: MPD 4.1)**

The generation of concepts or design proposals is the initial step where the manifestation of the product begins. In the context of SWS, the manifestation began with rough sketches of modifications based on the new product design specifications that were
identified and established during phases two and three. The modifications were concentrated in components where the user product interactions and visual perceptions mattered. The modification sketches were further developed and finalized for prototyping. The development of the product, as described earlier, had to adhere to the principles of modular product design (Refer to Section 5.2.4). The industrial design involvement in the investigation of MPD4.1 included ID2, 3, 4, and all attributes of CD1, CD2.1, 2.3, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), outcome (OC), and management (MG) played important roles in ensuring that the industrial design potentials were implemented appropriately in this phase of the modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 4</td>
<td>MPD 4.1</td>
<td>ID 2</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 3</td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 4</td>
<td>CD 1.3</td>
<td>OC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.9 – Application of industrial design in Phase 4 (MPD 4) of the modular product design process of SWS; this table is for the task MPD 4.1

**Evaluation:**

The evaluation outcome was concentrated on the industrial design potential (CD’s). Discussion and focus group were conducted for generation of improved concepts of the SWS design. The design staff members were selected based on their drawing skills and usage of computer software to conceptualise new or enhanced features of the SWS. The new concepts were presented to the project teams for further considerations. The researcher was responsible to oversee the conceptualisation tasks and ensured that the process adhered to general industrial design process. The whole exercise referred to InDFM standards. For this purpose, the researcher had centred the conceptualisation on the product feasibility and visual perception of the SWS. With regard to the product feasibility, ergonomics (human-factors) and user interactions were heavily studied throughout the process. The visual perception, on
the other hand, was based on operation requirement of the SWS, whereby product styling was given minimal priority. Therefore, the product looks and styling aspects were less important. The researcher treated both the feasibility and the visual perceptions as functional aspects of the new design for SWS. The selected new concepts were further developed to reach the point at which embodiment solution was found. The embodiment was checked to ensure that they fit the intended purposes. To do that, the researcher engaged a solid prototyping to visualise the new concept. At this stage, the selected design team had been familiarised with the InDFM process.

*Establishment of basic functional elements (Code: MPD 4.2)*

In the context of SWS, there was no involvement of industrial design in this phase as the basic functional elements have been established earlier.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 4</td>
<td>MPD 4.1</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

*Table 6.10 – Application of industrial design in Phase 4 (MPD 4) of the modular product design process of SWS; this table is for the task MPD 4.2*

*Evaluation:*

No evaluation was conducted for this phase.

*Establishment of basic physical components (Code: MPD 4.3)*

In this task, the SWS was designed and decomposed into basic physical sub-components and sub-systems that were capable of accomplishing the product functions and had to adhere to the modular design principles. The decomposition design of the SWS must allow the sub-components and the sub-system to be separated easily, and subsequently, be easily integrated or connected to other components and sub-systems within the product range. These sub-components and sub-systems should also be adaptable to other sub-components and sub-systems outside of the product range. In this context, the application of industrial
design in the basic physical components focused on user product interactions. Industrial design application in MPD4.3 included ID2, 3, 4, 5, 6, and all attributes of CD1, CD2.1, 2.3, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), outcome (OC), and management (MG) had been vital to ensure that the industrial design potentials were implemented appropriately in this phase of the modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 4</td>
<td>MPD 4.1</td>
<td>ID 2, ID 3, ID 4, ID 5, ID 6</td>
<td>CD 1.1, CD 1.2, CD 1.3, CD 1.4, CD 1.5, CD 2.1, CD 2.3, CD 3.1, CD 3.2, CD 4.1, CD 4.2, CD 4.3, CD 5.1, CD 5.2</td>
<td>EM, CA, OC, MG</td>
</tr>
</tbody>
</table>

Table 6.11 – Application of industrial design in Phase 4 (MPD 4) of the modular product design process of SWS; this table is for the task MPD 4.3

**Evaluation:**

The evaluation outcome had been similar to MPD4.1.

**System Optimisation – MPD 5**

The system optimisation phase (Code: MPD 4) involved four (4) tasks. The tasks were:

1. **System-level specification (MPD 5.1)**
2. **System-level specification impact on general functional requirements (MPD 5.2)**
3. **Similarity index and matrix (MPD 5.3)**
4. **Optimisation model and component grouping (MPD 5.4)**
System-level specification (MPD 5.1)

The output from the decomposition should enable the components to be arranged in modules and to be integrated into a functional system. The arrangement of components in the modules will give a vital impact on the overall design of the product. Industrial design involvements in MPD5.1 included ID4, 5, 6, as well as all attributes of CD1, CD2.1, 2.3, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), outcome (OC), and management (MG) played important roles in ensuring the industrial design potentials were implemented appropriately in this phase of modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 5</td>
<td>MPD 5.1</td>
<td>ID 4</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 5</td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ID 6</td>
<td>CD 1.3</td>
<td>OC</td>
</tr>
</tbody>
</table>

*Table 6.12 – Application of industrial design in Phase 5 (MPD 5) of the modular product design process of SWS; this table is for the task MPD 5.1*

**Evaluation:**

The evaluation outcome had been similar to MPD 4.1.

System-level specification impact on general functional requirements (MPD 5.2)

The general function requirements are affected by the system-level specification. This is due to the fact that some of the identified specifications might prevent the application of some desired general functional requirements although many may help satisfy some. Therefore, the impact of the system-level specification on the general functional requirements must be clearly identified. This is vital as it helps in developing products that will meet the
general functional requirements up to an appropriate level. The industrial design contributions in MPD5.2 included the followings attributes: ID6, as well as all attributes of CD1, CD2.1, CD3, CD4.1, 4.2, 4.3, and, CD5. In relation to the industrial design measures, *industrial design emphasis* (EM), *capability* (CA), *outcome* (OC) and *management* (MG) played important roles in ensuring the industrial design potentials were implemented appropriately in this phase of modular product design process.

<table>
<thead>
<tr>
<th>MPD Phase</th>
<th>MPD Task</th>
<th>I.D. Process</th>
<th>I.D. Critical Dimension</th>
<th>I.D. Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD 5</td>
<td>MPD 5.1</td>
<td>ID 6</td>
<td>CD 1.1</td>
<td>EM</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.2</td>
<td>CA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.3</td>
<td>OC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.4</td>
<td>MG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 1.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 3.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 4.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CD 5.2</td>
<td></td>
</tr>
</tbody>
</table>

*Table 6.13* – Application of industrial design in Phase 5 (MPD 5) of the modular product design process of SWS; this table is for the task MPD 5.2

**Evaluation:**

The evaluation outcome had been similar to MPD4.1.

**Similarity index and matrix (MPD 5.3)**

The degree of connection between the components or elements was measured before being used to establish a component groups to form a module. Industrial design contributions in MPD5.3 included ID6, as well as all attributes of CD1, CD2.1, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, *industrial design emphasis* (EM), *capability* (CA), *outcome* (OC), and *management* (MG) also played important roles to ensure the industrial design potentials were implemented appropriately in this phase of modular product design process.
Table 6.14 – Application of industrial design in Phase 5 (MPD 5) of the modular product design process of SWS; this table is for the task MPD 5.3

Evaluation:

The evaluation outcome had been similar to MPD4.1.

Optimisation model and component grouping (MPD 5.4)

Table 6.15 – Application of industrial design in Phase 5 (MPD 5) of the modular product design process of SWS; this table is for the task MPD 5.4

In order to establish the modules as a working component or a complete product, the components were grouped accordingly. The industrial design involvements in MPD5.4 included ID5, 6, as well as all the attributes of CD1, CD2.1, CD3, CD4.1, 4.2, 4.3, and CD5. In the context of industrial design measures, industrial design emphasis (EM), capability (CA), outcome (OC), and management (MG) played important roles in ensuring the industrial
design potentials were implemented appropriately in this phase of modular product design process.

Evaluation:

The evaluation outcome had been similar to MPD4.1.

The overview of the implementation of InDFM on the SCAR system is shown in Figure 6.10.

**Figure 6.10** - An overview of the InDFM on the SCAR system product development process

### 6.4 Summary of Investigation Outcome

The properties of the framework initially seem to be rather paradoxical or inconsistent. The methodology of industrial design itself emphasised on cognitive skills (Alvarez and Martinez, 2011; Meneely and Portillo, 2005), which relates directly to the human characteristics, needs, and interests, thus generating creativity and innovation beyond scientific reasoning. The InDFM seeks to expand the area of knowledge and revise the identity of the product through industrial design creativity and innovativeness by adopting the
strategy of ‘variety’ (Masson et. al., 2010; Guilford, 1966), which is the ability to propose a wide range of possible forms from a given conceptual brief. The implementation of InDFM in the project had given the design team the option to expand the functions and the appearance characteristics within the existing design concept, as well as in facilitating the application of creativity techniques and innovative design function of industrial design throughout the entire process.

The InDFM implementation on the SCAR weapon system (SWS) is discussed based on two (2) main justifications – Analysis of Implementation function and compatibility with existing process, as well as Similarity evaluation of framework configuration.

Although the implementation of the InDFM initially seemed to be a relatively complex task, a comprehensive functional description of the framework was proposed and explained (Refer to Chapter 5, Sections 5.4 and 5.5; Refer also to Figure 5.6) to associate the analysis of the possible InDFM functions within the modular design process. In supporting the functional description, the subscripts and the implementation codes were added to the generalised descriptions of each design and development stages, such as those that assist in the implementation start-up.

Meanwhile, the Product Definition (MPD1) stage involved the company’s strategic planning exercise, i.e., making decision to include (or exclude) industrial design in the modular product design process. If the decision was made to include industrial design – the scale of industrial design measures (EM, CA, MG, and OC) must be determined prior to the induction of the project definition. For this research, only EM (Industrial Design Emphasis) was applicable as the other measures were only significant in the next following stages. Besides, the analysis of process compatibility must be conducted against the company’s process documents (Refer to Index 4) if retrospective implementation of the InDFM is required in the existing design and development process. For this particular design project, the Customers’ Needs Analysis (MPD2) tasks were already defined by the customer (Refer to Chapter 6, Section 6.2) and the initial product functional requirements were already established prior to product design and development request. The industrial design measures involved EM, CA, and MG at all stages of MPD2. Moreover, the OC (outcome) measure was not conducted at this stage because there was basically no need of tangible output at this stage. At this stage, the potential of industrial design in the aspect of customer and functional requirements investigation had been concerned with product usability (CD1) and appearance.
(CD2). However, CD2.2 was excluded as the code referred to pride of ownership, image, and fashion aspects. On expanding the area of knowledge, the design team also conducted investigations for potential new customers and functional requirements. This stage also saw the design team conducting analysis on the SWS competitions, which were vital data for any possible product enhancement opportunities. These data could also be used to formulate new product variations. In addition, grouping and prioritising the needs requirement stage had been varied based on product operational and physical configurations. This stage determined the variations of the product from the basic configuration up to the specialized configuration for a specific combat operation. The product variants derived from this stage must be able to satisfy the specific needs of the customers, on both the functionality and appearance aspects. Moreover, the task of satisfying the needs was vital and highly emphasised as dissatisfaction on the required needs could lead to design and technical revisions of the entire product system. The design team was always alert of this circumstance, and the InDFM standards further established the alertness.

As for the Product Requirement Analysis (MPD3) stage, the basic functional objective of the product was determined by the customer. However, further discussions were also done with the design team to propose a secondary objective in case required. In the existing product design process that was employed, the design team did not conduct any basic product functional analysis because the basic product functions had been established. The implementation of the InDFM opened a new approach to this task as the design team was able to propose alternative functional applications through modifications of the product configuration in order to meet a variety of other operational functions, such as close range combat, long range shooting (sniper application), and non-ballistic application like target marking and less lethal weapon. The proposals for alternative functional applications, however, experienced several major constraints, particularly in relation to component modularity and compatibility issues. In addition, the industrial design involvements included all elements of CD1 and CD2, except CD2.2, which was irrelevant to the operational requirement analysis. Similar to MPD2, the industrial design measures involved EM, CA, and MG at all stages of MPD3. The OC (outcome) measure, however, was not conducted at this stage because there was basically no need of tangible output at this stage. Moreover, the industrial design involvement included more elements (Refer to Tables 6.7 and 6.8). The new elements for consideration included CD3 (Cost – which considered cost benefits and trade-off, as well as the appropriate use of resources involved in the design process), CD4
(Production – which considered the appropriate use of material, tooling and production techniques, as well as product packaging), and CD5 (Product life-cycle – which considered the product life-cycle planning and the appropriate material selection to ensure sustainable design). Meanwhile, in MPD3: 3.3, several requirements were identified and assigned based on their importance – customers’ needs for specific components, accessories, and the procurement quantity were included in the requirements. The highest priority requirement was to rectify the limitation of older rifle models through improved basic features in the new design. Furthermore, the System Decomposition (MPD4) stage included the creative potentials of industrial design. The generation of conceptual ideas for this project had been limited by the general function requirements that had been set by the client. However, the creativity of the Industrial Designers was concentrated on enhancing the user product interaction and appearance of the product for specific operation. The ideas were further developed to reach a point where embodiment solution was discovered. Besides, the final design of the product allowed integration and connection of sub-components (and sub-systems). Most aspects of the industrial design process and critical dimensions had been applied as well (Refer to Figure 6.11), and in addition, all industrial design measures were considered. Lastly, the system optimisation stage (MPD5) established the modules as a working component and a complete product, while the output from the decomposition enabled the component to be integrated into a functional system.
Chapter 7

7. Discussion

Objectives: This chapter brings together the issues that sparked the requirement for a new research into a dedicated methodology within the field of industrial design and prior to the outlining of the final outcome. The discussion encompasses the significance of the research that elaborates its novelty and contributions towards the academic society, product organisation, and industrial design professional. At the end of the chapter, a proposal on future work of an enhanced InDFM is explained.

7.1 The Need for a Formal Industrial Design Methodology in Modular Product Development

The adaptation of a mass customisation approach for production of user-driven products is deemed obligatory by a product manufacturer as the market has been saturated by similar products that do not necessarily meet customer requirements (Bardakci and Whitelock, 2003; Westbrook, 1993). Furthermore, mass-production approach is no longer relevant in the fast changing demand for consumer products and services as the turn-around time for products and services today is considerably shorter compared to ten years ago (Zimmerman, 2011, Pine et. al., 2010). This is especially apparent in the electronics and telecommunications industries where the competition is intense. Besides, product and service customers are becoming both cost-conscious and demanding, which has led to an increased awareness and greater access to similar products. This situation is continually increasing in competition and highly price sensitive. Thus, customising products in large amount to meet the customers’ demand has also led to the need for new mass customisation approaches, which are practicable in all areas of research, development, and design of products. This has led to the introduction of product modularisation approach.

As described in Chapter 3, Section 3.5.2, product manufacturers can use many methods to achieve mass customisation, but the best method of transforming a product;
ranging from ‘one of a kind’ design, is through the adaptation and modification of a standard product to meet a specific customer’s needs. The adaptation and modification of a standard product means that the product system needs to be configured and designed to be modular as possible. The term that basically refers to product design and development process that result in the creation of products with different complexities using similar components is ‘modular product design’. Modular product design is a design process dedicated to the design of products with a modular architecture. The process of modular product design is distinctive in its conceptualisation and integration stages in comparison to a standard product design process (Du et. al., 2001; Garud et. al., 2003). Furthermore, the process of creating a modular product system is complex; and literature related to modularity indicates that certain rules must be adhered to. One such rule relates to design, whereby the significance of a module’s architecture, interfaces, integration protocols, and testing standards are imperative. So how does industrial design becomes part of the modular product design and concurrently adhere to this rule?

To apply industrial design to modular product development, the company’s management must consider the strategic importance of industrial design to their product. These considerations should be used as the driver for industrial design application, and therefore, industrial design should not be strained into the final design at the end of the design process. In addition, industrial design should be applied at the core to all design elements throughout the entire design process (Copper et. al., 2011; Masson et. al., 2010; Candi and Gemser, 2010; Gemser and Leenders, 2001). Besides, industrial design methodology is needed in the management of design processes that emphasises user-driven aspects in order to optimise the function, value, and appearance of products, as well as systems, for the mutual benefit of both user and manufacturer. Contrary to some opinions by design practitioners and academician who stated industrial design as a practice (Masson et. al., 2010; Candi and Gemser, 2010; Gemser and Leenders, 2001), the researcher considers industrial design as a complex design action that is conducted systematically with defined framework, standard, and processes. The literature reviews conducted by the researcher revealed that the majority of product modularity developments are dominated by architectural and engineering aspects, and little suggests that industrial design involvements are essential although some products, such as modular furniture and toys, are based entirely on industrial design discipline. The discipline of architecture and engineering have optimised the application of the modularity concept since the 1930s (Russell, 2012) in buildings and engineering product
designs, thus portraying the concept of modularity as their exclusive domain. However, in order to meet the visual and tangible elements of modular product, the management of design process needs an appropriate methodology that specifically emphasises not only achieving customer satisfaction based on visual appeal and an interaction experience, but also solves the problem of innovation and the need to tap the hidden value in the brand. The application of industrial design methodology has been known to successfully enhance the features of a product visually and technically, as demonstrated by Apple, Samsung, and many other product companies across a broad range of products. Moreover, it is a big challenge for industrial design to be incorporated into product modularity design as there is currently no formal framework and guideline for its incorporation. Product modularity design, by itself, is a complex technical design process that leaves minimal room for designers to manoeuvre visual and interaction aspects within the design process. The lack of guideline information has led many modular product organisations to apply an ad-hoc approach to industrial design, with most of the organisations choosing to force the visual and interaction elements at the final stage of the design process (Gemser and Leenders, 2001; Veganti, 2008). Industrial design integration at the final stage of the design process will lead to difficulty in assessing the quality and results of industrial design services.

Furthermore, the benefit gained by product organisations from integrating industrial design into new modular product development processes is also immensely significant. However, little has been offered on how to integrate industrial design into strategic new-product development and innovation in the actual practice (Cooper, 2005, 2001). In order to access the full benefits of industrial design, product organisations must first understand the barriers to the adoption of design thinking in a typical new product development organisation. As an element of design, the researcher believes that industrial design should be put on priority as an innovation activity that complements Research and Development (R&D), whereby the process of industrial design possesses the ability to transform R&D output into commercially viable and tangible products, thus bringing innovation closer to user needs. The issues mentioned by the researcher, however, did not emerge from a company’s strategic product planning on the basis of any drawback in industrial design potential, but rather on the misconception of the methodology by the management of the company. This is apparent in the findings retrieved from the investigation on the perceived importance of industrial design functions (Refer to Chapter 4, Section 4.3.1.1), which summarised the need of industrial design as strategically non-essential; a perception that might be overturned if there is a formal
principle to apply industrial design. Besides, a specific challenge in synthesising research on a dedicated industrial design framework for modular product design emerged from inconsistencies and imprecise definitions of industrial design (Candi and Gemser, 2010). Successful product companies, on the other hand, are generally secretive about the design process that they use, whereby the design process itself could be regarded as a trade secret. The apparent lack of knowledge in applying industrial design mainly reflects the desperation of using an ad-hoc approach. Apart from the mentioned issues, the researcher discovered that many product companies have misconceptions towards industrial design, where the term is often associated with product design, thus ignoring its potential in other aspects of product development process (Refer to Chapter 4, Section 4.3.1.2). The product companies also suffer from a lack of common understanding of what industrial design actually entails, or what value it can offer their business.

7.2 Novelty

The Industrial Design Framework for Modular product design (InDFM) is a dedicated design framework for applying an industrial design methodology to modular product design. The novelty of the research into this domain is motivated by evidence that industrial design plays vital roles in innovation management (Dell’Era et. al., 2010; Dell’Era and Verganti, 2009, 2007) that underlines designer’s sensitivities to the user’s emotional needs. Therefore, the researcher considers that industrial design applications in highly technical design processes, such as the modular product design process, could provide a design-driven innovation into the process to complement the engineering driven innovation. The combinations of both innovations were proven to enhance the visual, interactive, and the feasibility contents of a modular product apart from providing a broader perspective to the objective of product modularity.

Besides, the researcher perceived InDFM as a route to creative innovation in the engineering field. Application of InDFM provides new depth in modular product design as it enables the design of new values and not merely features of products, as shown from the results of the framework application (Refer to Chapter 6, Section 6.4.2.1 and Section 6.5). InDFM also indicated that modular product design is a collective affair that involves a multi-disciplinary field, where the contributions of other expertise are vital as well. This has
triggered exploratory collaboration that also stimulates the creation of new values in modular product design (Refer to Chapter 6, Section 6.5). However, organising a collective design affair is delicate as it could involve a major transformation in the structure of the design team. With the new values, come new business opportunities, joint expansion of knowledge, and propositions. Moreover, the traditional and restrictive approaches in engineering design have shown difficulty in accounting for creative and innovative solutions to users’ centred issues. Engineering, designing, and marketing fields differ enormously between one another, but with the application of InDFM, the misunderstandings and disagreements due to restrictive views of design can be avoided (Cagan and Vogel, 2012; Phillips, 2004).

7.3 Contributions of InDFM

The current challenges regarding design reasoning has introduced the research into InDFM on both academic and commercial domains. Research into this domain has created a new challenge to investigate modular product innovation through industrial design. The research opportunities are derived from a number of significant gaps in the existing relationships between industrial design and engineering design, as well as between industrial designers and engineers. In general, it is very difficult to assess industrial design on its quality and results, especially for an engineering product that is modular. There seems to be no significant contribution of industrial design services in modular product design and research on industrial design as an element of innovation in modular product design and development is relatively non-existent. Hence, it is difficult to identify the rationales of industrial design in modular product design.

Furthermore, the development and the introduction of the InDFM have been anticipated to contribute to three (3) major groups; Product Organisations, Design Practitioners, and Academia. The contributions of InDFM are described as the positive impacts that it has on these three groups, while the negative impacts are described as the drawbacks of implementation and the possible improvements that are consequently shown for InDFM. The contributions and implications are described in the following sections.

1. **Product Organisation** – It is imperative that a product organisation should have a long term strategic plan for product design and development. Without the strategic plan, a
product organisation risks its chance to compete in the already highly competitive product market. As the current trend of product development has been focusing on mass-customisation; product organisations have few strategies to adopt in order to react to a variety of proliferation and complexity (Abdelkafi, 2008). Out of those strategies, product modularity had been identified as the most effective and efficient pursuit of mass-customisation (Piller and Tseng, 2010; Blecker and Friedrich, 2006; Kratochvil and Carson, 2005). However, going modular has not been proven to be a cost effective strategy for product generation (Garud et al., 2003). Conceivably, the best proven methodology for cost effective product generation is industrial design (Cuffaro, 2006; Booker et al., 2001). The study and research on systematic application of industrial design potential in modular product design has not been established by other researchers either from the industry or academic. The novel initiative by the researcher has created InDFM, a framework that provides a systematic methodology for industrial design in the modular product design process. Moreover, InDFM has been specifically designed to facilitate product organisations with creative innovation and cost effective ways to enable modular product design and generation in rapid succession. Product organisation with in-house design facilities will benefit more from InDFM as it provides comprehensive guidelines and standards for industrial design, which had been lacking in the existing modular design process. As of any new product development framework and standards, training on the implementation of InDFM is required. Based on the research validation, the implementation of InDFM was without difficulty, and the simplicity of the framework makes it easily understood, even if the in-house designers are not trained Industrial Designer or from an industrial design background.

2. **Design Practitioners** – Design activities are the activities used to conceive and formulate innovation; traditionally divided into R&D, engineering, industrial design and marketing, but often without adequate theoretical framework. From a design practitioner’s point of view, there is actually no specific design approach that can be used by all design practitioners because different sets of design projects involve different approaches. However, there is a need for a generic methodology for each design project that involves different architectures (Asan, et. al., 2004; Baldwin and Clark, 2000). Product architectures, such as integral and modular (Refer to Chapter 3, Section 3.4), require specific methodologies, and the integration of the methodologies with other design theory and practices, such as industrial design further adds complication to the already
complicated methodology. Without a systematic design framework and standards, designers will have no existing design rules for reference. The development and introduction of InDFM into an existing or conceptual process has provided design practitioners with a systematic design methodology to integrate industrial design within modular product design. Implementing InDFM in modular product design process also presents a tool for innovation that facilitates the revision of object identity, breaking away from the existing design rules, and generating new rules (Markman and Wood, 2009; Baldwin and Clark, 2000). Moreover, InDFM refers to a new approach of design that still maintains all traditional design functions. The implementation of InDFM by design practitioners, particularly those in the field of engineering design, will carry their existing design process to new heights by creating a new kind of design process portfolio that envisages strategic (Cultural and regional) importance as its key goal. The application mechanism of InDFM in this context enables flexibilities for design practitioners whose offices are normally scattered worldwide to capture the regional market, which is generally different in terms of culture and psychological needs of the customers (Refer also Chapter 3, Section 3.3.3; Chapter 5, Section 5.4.1; and Chapter 6, Section 6.5). Nonetheless, an important task for design practitioners is to identify and understand the cultural elements that influence the acceptance of product features and characteristics for a specific market. As such, the enhanced design process is considered as a strategic tool for user-centred innovation that is holistic and multidisciplinary problem-solving approach, taking into account user needs (including cultural and psychological), aspiration, and abilities as its starting point and focus (Lu & Wang, 2011; Arundel et al., 2008, Nordic Innovation Centre, 2008; Sotamaa, 2004).

3. **Academia** – Industrial design has long been regarded as the provider of visual and utility elements in consumer products. Research into the emotional needs of users in engineering products also needs further investigation in order to develop a comprehensive model that mediates influence and reaction. However, the current approaches for study taken by industrial design academics and researchers in most universities segregate the bachelor degree courses of industrial design and engineering. It is rarely seen in university taught courses that industrial design and engineering are integrated to produce a dedicated course that is cohesive and coherent. The study of integrated courses of industrial design and engineering, or with other courses is mostly conducted at a postgraduate level, generally by research. Currently, taught courses for
industrial design are mostly conducted for a Master Degree level and none at the Doctoral level. In fact, postgraduate researches on design and engineering have been conducted in many areas, including researches on the relationship of cross-functional experts in a project team (Pehlivan, 2007; Sara, 2005). However, there is lack of literature about the involvement of industrial design in modular product design, which suggested this as a potential research area for the researcher. As mentioned in the previous chapters, product modularity is rarely connected with industrial design, except in furniture and toy designs. Therefore, it is imperative that a research into these domains is conducted in order to establish a substantial connection between industrial design and modular design in a wider scope of product design and development. Academically, there is a need to set up a fundamental theory or ground-rules for a systematic application of industrial design. Besides, academic research provides theoretical incentive and guideline for industries to initiate such a project. Academics embarking on this research can generate actual information and knowledge on this particular domain, as such information and knowledge will eventually benefit the industry as a whole.

7.4 Limitations and Necessary Adaptations of the Research

In the global context, innovation is the only way of satisfying the social, environmental, and economic aspects of development, besides creating new added values to saturated product market (Masson et al., 2010; Dell’Era and Verganti, 2009; Chesbrough, 2003; Adner and Levinthal, 2001). Additionally, innovation, in the context of design, is very synonymous with styling, fashion, gadgets, and technology, but innovation by itself does not really mean anything unless there are values that form an integral part of it. For modular product design, as a productive activity, there is a greater need for new methods to assess its innovation value. In the academic sphere of the security industry, the researcher discovered that the industrial design potential in modular design of assault rifle had not been vigorously studied so far. This product had been designed and developed on the basis of enduring practical experience of the designers, some of those with sound military background and are familiar with most assault rifles technicalities. Due to this ‘tradition’; innovation had been minimal and in the current product development setting, innovation has often been associated with issues of change, uncertainties, and risks. With the development of a systematic methodology, such as InDFM, there is already a way to minimise the uncertainties and risks.
Additionally, InDFM can be considered as a survival strategy for product companies to compete with distinctive products in the market.

As the competition for product dominance is very intense, there is no company that is willing to expose their design methodology to their competitors, and there is also no company that competitors can immediately copy or use as a reference for their design capability and method. Alternatively, InDFM is an adaptable methodology, thus making innovation of modular product design through industrial design accessible to any company. Nevertheless, although InDFM offers huge potential for industrial design innovations in modular product design, there have been barriers in executing and realising a comprehensive study like this research. The research conducted in this thesis specifically focused on the application of InDFM on modular product design within industrial design capability of a selected assault rifle design (Refer to Chapter 1, Section 1.6, and Chapter 3, Section 3.7.1), and also taking into account the areas of the modular product manufacturing where complex product engineering system and operation software are hugely applied. However, these areas are considered as highly defined engineering design areas that the researcher identified as least relevant for industrial design to contribute due to the characteristics of their operation processes. Furthermore, forcing industrial design into complex engineering design environment may affect the engineering integrity of the design itself. Another factor the research limits investigation into was product costing. The cost benefits and trade-off of implementing industrial design in modular product design process were not investigated as it is difficult to understand the cost implications of product modularisation due to the extensiveness of its process, particularly in highly complex product system. Besides, the level of design complexity of the modular product also influenced the final production cost (Refer to Chapter 3, Section 3.6.4). Therefore, the research and the development of InDFM excluded the cost analysis of modular product design.

Apart from that, the limitations encountered during the research were mostly engineering based within the tasks involving manufacturing of the rifle components through automated machining process. Therefore, it was difficult to determine the application of industrial design in this process, although there are a handful of innovation proposals to enhance the industrial design aspects in production environment, such as improvement on user friendly facet and the ergonomics of operation. In the current production environment, however, industrial design potential in modular design of machine tools and software system
are in fact unheard of. Associated literatures, data records, and investigations reports are
diminutive, thus leaving the researcher to limit investigations in areas of product component
design and not machine tools and manufacturing software systems.

Nevertheless, the standard configuration of a common assault rifle, such as an M4 Carbine and SCAR, consisted of seven (7) major components – Butt Stock assembly, Body Upper part (including carrying handle assembly), Marker’s core assembly, Lower body part, Barrel (including fore grips), Grip handle, and Magazine assembly (Refer to Figure 7.1). Out of these components, nearly all of them were manufactured via automated machining process, except the Butt Stock (Injection moulded plastic) and Magazine assembly (Stamped metal). The employment of modular design should see the jointing method and the surface of these components being unified or standardised in the most preferable case, while maintaining allowable assembly accuracy and acceptable joint stiffness under repeated use of the modules. Since the major design works of the components were done in computer-aided design (CAD) software; the 3D data were easily translated and fed into the automated machining and manufacturing system. Basically, this is where the involvement of an industrial designer ends as the selection and description of machine tools to be utilised is now determined by the manufacturing engineer.

![Figure 7.1](image.png)

Figure 7.1 – The configuration of the seven (7) major components of a standard M4 Carbine assault rifle

The control of machine tools and software systems had been a crucial issue, particularly from the aspects of integration and disintegration of the machine tools as a whole, and determining the manufacturing system to be used in manufacturing of the rifle
The data available from the 3D design drawings needed to be translated into CNC data in order for the machining processes to be initialised. The tasks were all conducted by manufacturing engineers and little to almost no contribution from industrial designer. For example, the modularity consideration of machining space and the cutting bits must be investigated in the unit construction of an automated turning machine to display the frequency distribution of the travelling ranges of the carriage and cross slide, as well as the structural configuration and rotating axis of the turret head of the automated turning machine. The manufacturing processes and software systems for both the rifle types – M4 Carbine and SCAR – were set to modular manufacturing system as both rifle types possessed almost similar components configuration. Although this stage is one of the major parts of a new product development process, the decision to include it as part of InDFM development strategy could not be done as industrial design measures could not be detected or determined at this particular stage. However, the researcher believes that this issue could be studied in future related research or continuation of this research in order to establish a detailed industrial design guide by merging practical experience and academic knowledge. In this context – complex and calculated engineering process – the researcher had been restricted to focus on the practicability and user-centred aspects of the product design, thus leaving product engineering and manufacturing system, as well as computer operating software and system for potential future research.

### 7.5 Future Work

The methodology of industrial design has been increasingly becoming more widespread despite the fact that companies are adopting new technologies. Industrial designers have managed to maintain design reasoning by merging innovative design systems based on user emotions with engineering systems (Schlick, 2009; Pahl et al., 2007; Cross, 2001). The InDFM has managed to integrate industrial design with modular product design process, which translates this notion. However, the integrated process is not to be confused with scientific approaches. In fact, this is almost entirely a creative artistic approach in engineering methodology that does not interfere with the technological and mechanical innovativeness of engineering. This is another innovative approach that is rather cost effective in both its execution and results. Given the limited time in assessing the InDFM in an actual design and development situation, this new methodology has been successful in
providing a formal systematic approach to industrial design in an unfamiliar ground. This has proven that the potentials of the new framework, methodology, and standards are highly significant in supporting and enhancing the existing and new modular design processes. This situation has prompted the researcher to embark on an enhanced version of the InDFM in order to progress alongside with the ever changing technological advancement in the design and development arena.

Figure 7.2 – The academic research phases required to continue the work begun in the InDFM research to develop e-InDFM.

This novel approach to promote industrial design methodology in the engineering domain is anticipated to be further recognised through technological representation apart from the current representation of InDFM. In this notion, the researcher is working to develop an interactive InDFM that utilises a dedicated software package or webpage that is publicly accessible for use and referred by any potential modular product company. The future version of InDFM shall be stated as e-InDFM and utilises similar mechanisms with enhanced capability and features that should enable the user to immediately decide on the appropriate
steps to industrial design within their modular design process. With the availability of e- InDFM, product organisations that intend to implement industrial design in their modular product design process may access the e-InDFM software to predetermine the potentials of industrial design at any phase of design development. The following paragraphs provide the general elaborations of the proposed research phases required in creating the e-InDFM (Refer to Figure 7.2).

**Phase 1 – Discussion and selection of enhanced InDFM concept**

Discussions on the proposed concept of the enhanced InDFM are crucial. During this stage, the proposed potential users and target market have been identified. In addition, the needs of the users and target market are also identified. The discussion scrutinised the proposed new concepts for its practicability, and any potential competitive products are reviewed. Once the product concept is decided and selected, the product specifications are defined. This stage provides the foundation for the development effort where development of project is outlined. Moreover, the researcher anticipated the future development of the enhanced InDFM should go for a digital interactive approach, utilising either specially developed software or commercially available template from the internet.

**Phase 2 – Identify the system development task to develop digital InDFM**

In this phase, a system development, which is a set of activities used to build an information system for the enhanced InDFM, is defined. A set of activities had been performed, which generally included – Review and approve project requests/proposal; Prioritise project proposal; Allocate resources (people, money, and equipment); and form a project development team. The system development tasks then go to the analysis stage that will include feasibility study and user analysis. The main purpose of this stage is to measure the suitability of the system to the users’ organisation, whereby several factors are evaluated, such as – Operational feasibility - measures how well the proposed information system will work; Schedule feasibility - measures if the established deadlines for the project are reasonable; Technical feasibility - measures if the developer has or can obtain the computing resources, software services, and qualified people needed to develop, deliver, and support the system; and Economic feasibility - measures if the lifetime benefits of the proposed
information system will be greater than its lifetime costs. The system proposal also assesses the feasibility of each alternative solution – Buy retail software; Build custom software; Use web apps; or outsource.

**Phase 3 – System design (input InDFM mechanism based on conventional version)**

The design phase shall involve two (2) major activities – Acquiring hardware and software; and Developing detail of the system. Once the activities are determined, design and development of the system can proceed by confirming the technical specification of the system, and followed by the database, input and output, as well as program design. All the components of the InDFM mechanism are based on the conventional (original) version. The final design of the system is selected for construction of a mock-up model before proceeding to developing a working prototype of the e-InDFM. The prototype will be used as proof of concept as well as to test and evaluate the essential functionality of the system design.

**Phase 4 – Input product to be designed**

Identification of major product industry is conducted to determine the list of products to be employed as input into the system design. Appropriate to this research, preference will be given to modular products, which are then divided into specific categories, for example – consumer modular product; and industrial modular product. Generally, the flow of the interfaces selection may look like this: Product Type ➔ By Industry ➔ Device Type (Refer to Figure 7.3).

**Phase 5 – Input the course of action**

This phase is the most important part of the system design as it determines the InDFM course of action taken by the user on implementing industrial design in their modular design process. The interface selection continues, which may look like this: InDFM Implementation Stage ➔ ID Critical Dimension ➔ Course of Action (Refer to Figure 7.3). As mentioned in Section 7.4, the factor related to product manufacturing and machine tool may be addressed in: InDFM Implementation Stage ➔ ID Critical Dimension ➔ Production ➔ Tooling ➔ Course of Action (Refer to Figure 7.3). Meanwhile, the factor related to product costing may be
address in: *InDFM Implementation Stage* ›› *ID Critical Dimension* ›› *Cost* ›› *Cost benefits and trade-off* ›› *Course of Action* (Refer to Figure 7.3).

In addition, the system design with simple computer interfaces and links will facilitate rapid decision making among the project team members (Refer to Figure 7.3). The proposed development of the *e-InDFM* is anticipated to provide users with simple and user friendly access to a useful design methodology tool through digital interactive interfaces. With future advancement in computer software technology, the researcher is adamant to continuously develop InDFM in digital formats.

**Figure 7.3** – An example of simplified interface diagram of the interaction between each attribute in the *e-InDFM* system
Bibliography


Cunningham, W., 2012, *New platform brings Volkswagen and Audi models closer*, CNET, CBS Interactive Inc.


Desai, G.; 2007; Activity Theory: A Framework for Ethnographic Research for Industrial Design; International Conference on Engineering and Product Design Education; Northumbria University; Newcastle Upon Tyne, United Kingdom


FedBizOpp.gov; 2011; *Combat Assault Rifle and Enhanced Grenade Launcher Module*; Department of the Navy; Solicitation Document; www.fbo.gov


Freeman, C., 1987, *The Economics of Industrial Innovation*, Francis Pinter Publisher, London


John, D., 2008, *Do Data Characteristics Change According to the number of scale points used? An experiment using 5-point, 7-point and 10-point scales*, International Journal of Market Research, 50 (1), Page 61–77


Nordic Innovation Centre, 2008, *User-Driven Innovation. Context and cases in the Nordic Region*, (b)


Sanborn, J. K.; August 11, 2013; *Corps seeks modular stock for sniper rifle – M40 upgrades make it ergonomic, deadly*; Copyrights © 2014 www.marinecorpstimes.com


Stone, R. B., 2000, A heuristic method for identifying modules for product architectures, Design Studies, 21, Page 5-31


Tovey, M. ; 1997, Styling and Design: Intuition and Analysis in Industrial Design, Design Studies, 18(1), 5-31


Westbrook, R., Williamson, P., 1993, Mass customisation – Japan's new frontier; European Management Journal; Vol. 11 – Issue 1; Page 38–45


Index 1

Questionnaire I
Establishing Industrial Design Framework to Support Product Decomposition and Integration Models for Modular Product Development

Firdaus Abdullah m.f.a.abdullah@lboro.ac.uk

Introduction: This interview forms part of a PhD research into establishing an industrial design framework to support modular systems development. A modular systems development involves decomposition of product components and integration of them to achieve the intended functions. The outcome/results to this task will be used to set up an outline that is necessary to support a methodology in developing an initial framework proposal that forms the principle of this research.

Objectives of interview:

- To identify the relative timing of industrial design in the product decomposition stage of the modular product development process currently being applied.
- To identify the relative timing of industrial design in the integration models stage of the modular product development process currently being applied.
- To identify the core functions of industrial design in each of these stages of the modular product development process currently being applied.
- To investigate the involvement of industrial design in correlating the general functional requirements into modular system development in the product development process currently being applied.

Terminology

Industrial Design – The professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer (IDSA).

Modular Product – A modular product platform definition of modularisation is ‘decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies (Ericsson and Erixon, 1999).

Part 1 – Your details

As one of the selected company to participate in this research, we would like to thank you for taking part in this interview. Before we proceed, we will need some information about you to obtain more accurate results. This information will be used solely for this research purposes and will be kept strictly confidential.

Company:
Nature of business:
In-house Industrial Design department/section:
Your name:
Your job title:
Your role and responsibility:

Thank you.
Part 2 - Questions

Your answers on this interview should purely be based on your general professional opinion relative to your experiences in the field of modular product development and industrial design.

1. General

1.1. What is the core function of the Industrial Design (ID) department/section in your company?

1.2. Is the ID department/section in your company involved in any particular modular product development?  
☐ Yes  ☐ No

1.3. In your own terms, could you describe a modular product?

1.4. What is your opinion on product modularity?

1.5. Do you think that ID should be involved in the systems development of a modular product? 
☐ Yes  ☐ No

If No, please state your reason and proceed directly to 3.

2. Modular Systems Development

In this section, all questions will be based on the diagram as shown in figure 1. This diagram shows the stage where modular systems development is done. The modular systems development stages are primarily involved in product/concept analysis and integration. These are the stages where the product is decomposed into its basic functional and physical elements, arranged in modules and integrated into a functional system.

![Modular Systems Development Stages](image)

**Figure 1** – Modular systems development stages in modular product development process

2.1. Product/concept analysis

2.1.1. Is ID in your company involved in this stage of modular product development?  
☐ Yes  ☐ No

If NO, please proceed to 2.1.3

2.1.2. (Yes) Is ID involved in any of the following tasks? Select the appropriate tasks.  
*In product physical decomposition*

☐ Decompose product into sub-systems.  
☐ Decompose product into physical element.  
☐ Identify basic physical components.  
☐ Design basic physical components.
Design interfaces of physical components.

In product functional decomposition

- Decompose product into functional element.
- Describe product’s intended overall behavior and functions.
- Identify component functions.
- Design component functions.
- Design logical arrangement (working principle).
- Conceptualise product function into action statement.
- Identify interfaces between functional components.
- Design interfaces of functional components.

Others, please specify:

2.1.3. (No) Should ID be involved in this stage of modular product development?
   - Yes  
   - No

2.1.3.1. (Yes) How should ID be involved in this stage of modular product development?

2.1.3.2. (Yes) So, if ID is not involved but you think it should be, could you explain why you think it is not?

2.1.3.3. (No) Why do you think ID should not be involved in this stage of modular product development?

2.2. Product/concept integration

2.2.1. Is ID in your company involved in this stage of modular product development?
   - Yes  
   - No
   If No, please proceed to 2.2.3.

2.2.2. (Yes) Is ID involved in any of the following tasks? Select the appropriate tasks.
   - Identify system-level specifications
   - Establish functional characteristics
   - Establish physical characteristics
   - Establish guideline to identify relationship of characteristics

   Functional characteristics
   - Identify main function(s) based on functional decomposition
   - Identify required operations and transformations in order to achieve the function.
   - Document the operations and transformations.
   - Categorise operations and transformations.
Physical characteristics
☐ Identify any physical constraints imposed on the product based on the requirement analysis.
☐ Identify possible arrangements and assemblies of components.
☐ Document the possible arrangements and assemblies.
☐ Categorise arrangements and assemblies.

2.2.3. (No) Should ID be involved in this stage of modular product development?
☐ Yes  ☐ No

2.2.3.1. (Yes) How should ID be involved in this stage of modular product development?

2.2.3.2. (Yes) So, if ID is not involved but you think it should be, could you explain why you think it is not?

2.2.3.3. (No) Why do you think ID should not be involved in this stage of modular product development?

3. Reflection of industrial design
Can you give some reflections on the overall success of ID in your company?

That’s all. Thank you again. Your time and patience are sincerely appreciated.
Index 1

Questionnaire II
Online Survey
Towards Establishing an Industrial Design Framework to Support Product Decomposition and Integration Models in Modular Product Development

©Muhammad Firdaus Abong Abdullah 2008
Towards Establishing an Industrial Design Framework to Support Product Decomposition and Integration Models in Modular Product Development

Firdaus Abdullah, Russell Marshall

Introduction: This questionnaire forms part of PhD research into establishing an industrial design integration framework to support product decomposition and integration models in modular product development. The outcome/results to this questionnaire will be used to support a methodology in developing an initial framework proposal.

Objectives:

- To find out the industries general perceptions/views towards the (possible) roles of industrial design in their current product development process.
- To identify the relative timing of industrial design process in each phase of the product (modular) development process currently being applied.
- To identify the actual core functions of industrial design in each phase of the product (modular) development process currently being applied.

Terminology

**Industrial Design** – The professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer (IDSA).

**Modular Product** – A modular product platform definition of modularisation is 'decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies (Ericsson and Erixon, 1999).

Part 1 – Your details

As one of the selected companies to participate in this research, we would like to thanks you for taking part in our survey. We would be grateful if you could supply some information about yourself to allow classification of your responses. This information will be used solely for this research purposes and will be kept strictly confidential.

Company and address:

Nature of business:

Your name:

Your job title:

Your role and responsibility:

Please proceed to Part 2 (overleaf). Thank you.
Part 2 - Questions

Your answers on this questionnaire are purely based on your general professional opinion relative to your experiences in the field of product modularity development and industrial design.

1 General

1.1 What products does your company produce?

1.2 Does your company have an in-house industrial design section/department?

☐ YES  ☐ NO

1.3 If YES, what is the core function of the section/department in your company?

1.4 If NO, what is the main reason for not having one?

1.5 In your own terms, describe a modular product.

1.6 What is your opinion of product modularity?

1.7 Do you think your company is producing modular products?

☐ YES  ☐ NO

1.8 If NO, please specify your product category

2 Modular Product Development Process

In this section, all questions will be based on the generic product development process as defined by Ulrich and Eppinger, 2003 (shown in Figure 1). The roles of ID in each phase of the modular PDP is identified from the three main functions of an organisation ie. marketing, design, manufacturing, and some other supporting functions. These functions are chosen because of their continuous involvement in the process.

![Figure 1 – The generic product development process (adopted from: Ulrich and Eppinger, 2003)]
2.1 Planning phase

2.1.1 Marketing functions – How should industrial design be involved? Check whichever apply:

☐ Defining corporate strategy
☐ Articulate market opportunity
☐ Defining market objectives and segment
☐ Specifying project mission statement
☐ Others. Please specify

2.1.2 Design functions – How should industrial design be involved? Check whichever apply:

☐ Consider product platform and architecture
☐ Assess new technology
☐ Others. Please specify

2.1.3 Manufacturing functions – How should industrial design be involved? Check whichever apply:

☐ Identify production constraints
☐ Set supply chain strategy
☐ Others. Please specify

2.1.4 Other functions – How should industrial design be involved? Check whichever apply:

☐ Research: Demonstrate available technology
☐ Finance: Provide planning goals
☐ General management: Allocate project resource
☐ Others. Please specify

2.2 Concept development phase

2.2.1 Marketing functions – How should industrial design be involved? Check whichever apply:

☐ Collect customer needs
☐ Identify lead users
☐ Identify competitive products
☐ Others. Please specify
2.2.2 **Design functions** – How should industrial design be involved? Check whichever apply:

- [ ] Investigate feasibility of product concepts
- [ ] Develop industrial design concepts
- [ ] Build and test experimental prototypes
- [ ] Others. Please specify

2.2.3 **Manufacturing functions** – How should industrial design be involved? Check whichever apply:

- [ ] Estimate manufacturing cost
- [ ] Assess production feasibility
- [ ] Others. Please specify

2.2.4 **Other functions** – How should industrial design be involved? Check whichever apply:

- [ ] Finance: Facilitate economic analysis
- [ ] Legal: Investigate patent issues
- [ ] Others. Please specify

2.3 **System-level Design phase**

2.3.1 **Marketing functions** – How should industrial design be involved? Check whichever apply:

- [ ] Develop plan for product options and extended product family
- [ ] Set target sales price points
- [ ] Others. Please specify

2.3.2 **Design functions** – How should industrial design be involved? Check whichever apply:

- [ ] Generate alternative product architectures
- [ ] Define major sub-systems and interfaces
- [ ] Refine industrial design
- [ ] Others. Please specify

2.3.3 **Manufacturing functions** – How should industrial design be involved? Check whichever apply:

- [ ] Identify suppliers for key components
- [ ] Perform make-buy analysis
- [ ] Define final assembly scheme
- [ ] Set target costs
- [ ] Others. Please specify
2.3.4 **Other functions** – How should industrial design be involved? Check whichever apply:

- Finance: Facilitate make-buy analysis
- Service: Identify service issues
- Others. Please specify

2.4 **Detail design phase**

2.4.1 **Marketing functions** – How should industrial design be involved? Check whichever apply:

- Develop marketing plan
- Others. Please specify

2.4.2 **Design functions** – How should industrial design be involved? Check whichever apply:

- Define parts geometry
- Choose materials
- Assign tolerances
- Complete industrial design control documentation
- Others. Please specify

2.4.3 **Manufacturing functions** – How should industrial design be involved? Check whichever apply:

- Define piece-parts production processes
- Design tooling
- Define quality assurance processes
- Begin procurement of long-lead tooling
- Others. Please specify

2.5 **Testing and refinement phase**

2.5.1 **Marketing functions** – How should industrial design be involved? Check whichever apply:

- Develop promotion and launch materials
- Facilitate field testing
- Others. Please specify

2.5.2 **Design functions** – How should industrial design be involved? Check whichever apply:

- Reliability testing
- Life testing
Performance testing
 Obtain regulatory approvals
 Implement design changes
 Others. Please specify

2.5.3 **Manufacturing functions** – How should industrial design be involved? Check whichever apply:

- Facilitate supplier ramp-up
- Refine fabrication and assembly processes
- Train work force
- Refine quality assurance processes
- Others. Please specify

2.5.4 **Other functions** – How should industrial design be involved? Check whichever apply:

- Sales: Develop sales plan
- Others. Please specify

2.6 **Production ramp-up phase**

2.6.1 **Marketing functions** – How should industrial design be involved? Check whichever apply:

- Place early production with key customers
- Others. Please specify

2.6.2 **Design functions** – How should industrial design be involved? Check whichever apply:

- Evaluate early production output
- Others. Please specify

2.6.3 **Manufacturing functions** – How should industrial design be involved? Check whichever apply:

- Begin operation of entire production system
- Others. Please specify

**That’s all.** Thank you again. Your time and patience have been sincerely appreciated.
Index 1

Questionnaire III
Questionnaire

Aim
Assessing the importance of Industrial Design in Modular Product Development.

Introduction:
This questionnaire forms part of my PhD research into establishing an industrial design framework to support modular product development.

The assessment of importance of industrial design to a user-driven and technology-driven modular product development is done by determining the importance along five main dimensions. The main dimensions are divided into several sub-dimensions. The five main dimensions are described in the questions set.

The objectives of this questionnaire are:
1. To identify the level of importance of industrial design in modular product development.
2. To grade the main dimension based on the identified level of importance.
3. To determine the factors that justified the importance.
4. To identify the dimensions where industrial designers input/involvement is mostly required.

Terminology

**Industrial design** – I.D is a methodology applied in the design and development of a product to achieve critical goals in utility, aesthetics, cost, production, and retiring, in order to ensure the success of the product for the benefits of both the producer and user.

**Modular Product** – A modular product is a product produced by integrating building blocks (modules) with specified interfaces.

Part 1 – Your details
We would like to thank you for taking part in this interview. Before we proceed, I will need some information about you to obtain more accurate results. This information will be used solely for this research purposes and will be kept strictly confidential.

Profession:
Organisation:
Industrial design experience:

**Part 2 – Questions**

Please choose the level of importance that you consider appropriate of industrial design involvement in the development of the selected modular product, and provide a brief justification.

- [ ] Commuter train interior (user-driven)
- [ ] Mobile phone (user/technology-driven)
- [ ] Assault rifle (Technology-driven)

**Level of importance (LOI)**

1. Never needed  
2. Can be considered  
3. Recommended  
4. Necessary  
5. Extremely vital

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Utility</strong></td>
<td></td>
</tr>
<tr>
<td>1.1 Ease of use – ID provides input to ensure a product is easy to use.</td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td>1.2 Ease of maintenance – ID provides input to ensure a product is easy to service and maintain.</td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td>1.3 Quality and quantity of interaction – ID provides input to ensure a product is operationally suitable for the user.</td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td>1.4 Novelty of user interaction – ID provides input of new data for improved development of new product.</td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td>1.5 Safety – ID provides innovative input on the safety aspect of a product.</td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>2 Aesthetics</strong></td>
<td></td>
</tr>
<tr>
<td>2.1 Product differentiation – ID provides input on aesthetics differentiators of similar product.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>2.2</strong> Pride of ownership, image and fashion – <em>ID provides input on how a product could embedded the pride of ownership, image and fashion to the user.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>2.3</strong> Communication – <em>ID provides input on how the design of a product should be able to communicate the corporate philosophy and mission of a company.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>3</strong> Cost</td>
<td></td>
</tr>
<tr>
<td><strong>3.1</strong> Cost benefits and trade-off – <em>ID provides input to determine the cost of a product.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>3.2</strong> Appropriate usage of resources – <em>ID provides input on development processes to avoid unnecessary cost.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>4</strong> Production</td>
<td></td>
</tr>
<tr>
<td><strong>4.1</strong> Appropriate use of raw material – <em>ID provides input on the material suitability of the product being developed.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>4.2</strong> Tooling – <em>ID provides innovative input on the tooling (mould) configurations of a product under development.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>4.3</strong> Manufacture and assembly – <em>ID provides innovative input on manufacturing and assembly process.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
<tr>
<td><strong>4.4</strong> Packaging – <em>ID provides input and design for attractive and innovative packaging.</em></td>
<td></td>
</tr>
<tr>
<td>Justification:</td>
<td></td>
</tr>
</tbody>
</table>
5 Product life cycle

5.1 Innovative design – *ID provides innovative input on how the overall design contributes and influences the life cycle of a product.*

Justification:

5.2 Material selection – *ID provide input on the appropriate material for a product to ensure recycle-ability and safe disposal.*

Justification:

That’s all. Thank you again. Your time and patience are sincerely appreciated.

©Firdaus Abdullah  
PhD Researcher  
Design Technology Department  
Loughborough University  
[electronic mail]  
Tel.: 01509 228315
Index 1

Questionnaire IV
Department of Design & Technology

Online Survey

Form 1

Research Title:
Towards Establishing an Industrial Design Framework to Support Product Decomposition and Integration Models in Modular Product Development

© Muhammad Firdaus Abong Abdullah
2008
Towards Establishing an Industrial Design Framework to Support Product Decomposition and Integration Models in Modular Product Development

Firdaus Abdullah
m.f.a.abdullah@lboro.ac.uk

**Introduction:** This questionnaire forms part of PhD research into establishing an industrial design integration framework to support product decomposition and integration models in modular product development. The outcome/results to this questionnaire will be used to support a methodology in developing an initial framework proposal.

**Objectives:**
1. To find out the needs of industrial design in the strategic planning of a product.
2. To identify the actual involvement of industrial design in the product design and development process.
3. To investigate the anticipated future application of industrial design in product design and development.
4. To identify the actual demand of industrial design services provided by industrial design practitioners/companies.

**Terminology**
*Industrial Design* –
The professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer (*IDSA*).

*Modular Product* –
A modular product platform definition of modularisation is ‘decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies (*Ericsson and Erixon, 1999*).’

**Your details**

As one of the selected companies to participate in this research, we would like to thanks you for taking part in our survey. We would be grateful if you could supply some information about yourself to allow classification of your responses. This information will be used solely for this research purposes and will be kept strictly confidential.

Company and address:

Nature of business:

Your name:

Your job title:

Your role and responsibility:

Please proceed (overleaf). **Thank you.**
Generic Product Development Process
In this section, all questions will be based on the generic product development process as defined by Ulrich and Eppinger (2003). The roles of Industrial Design in each phase of the modular PDP is identified from the three main functions of an organisation ie. marketing, design, manufacturing, and some other supporting functions. These functions are chosen because of their continuous involvement in the process.

![Diagram of the generic product development process](adopted from: Ulrich and Eppinger, 2003)

General
Your answers on this questionnaire are purely based on your general professional opinion relative to your experiences in the field of product modularity development and industrial design.

1. What products does your company produce?

2. Does your company have an in-house industrial design section/department?
   - ☐ YES    ☐ NO

3. If YES, what is the core function of the section/department in your company?

4. If NO, what is the main reason for not having one?

5. In your own terms, describe a modular product.

6. What is your opinion of product modularity?

7. Do you think your company is producing modular products?
   - ☐ YES    ☐ NO

8. If NO, please specify your product category
**Part 1 – Industrial Design in Product Strategic Planning**

Please rate the importance of functions in your product strategic planning according to the *Scale* as shown below.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Likert-type Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>2</td>
<td>Undesirable</td>
</tr>
<tr>
<td>3</td>
<td>Maybe</td>
</tr>
<tr>
<td>4</td>
<td>Required</td>
</tr>
<tr>
<td>5</td>
<td>Highly Applicable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Functions</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Research and Development (R&amp;D)</td>
<td></td>
</tr>
<tr>
<td>2. Organisation</td>
<td></td>
</tr>
<tr>
<td>3. Industrial Design</td>
<td></td>
</tr>
<tr>
<td>4. Manufacturing</td>
<td></td>
</tr>
<tr>
<td>5. Marketing</td>
<td></td>
</tr>
<tr>
<td>6. Information Technology</td>
<td></td>
</tr>
<tr>
<td>7. Engineering</td>
<td></td>
</tr>
<tr>
<td>8. Sales</td>
<td></td>
</tr>
</tbody>
</table>

**Part 2 – Industrial Design involvement in Product Development Process**

Please state √ either *YES* or *NO* for industrial design involvement in the integrated activities within your current product design and development process.

<table>
<thead>
<tr>
<th>Integrated Activities within Product Development Process</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Marketing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Product Research</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Product Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Product Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Quality Assurance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Component Supplier Chain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Maintenance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Part 3 – Anticipated Industrial Design Application**

Please state √ either **YES** or **NO** for the current and expected future roles of industrial design in your product design and development process. The future roles are based on the next Five (5) Years Product Design and Development Plan.

<table>
<thead>
<tr>
<th>Current Demand</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Product Researcher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Product Stylist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Technician</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Creative Leader</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Product Engineer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Future Demand</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Product Researcher</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Product Stylist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Technician</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Creative Leader</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Product Engineer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part 4 – Industrial Design Services**

Please check √ in the table below for the design services provided by Industrial Design practitioners in your organisation. You may check more than one (1) design services listed below.

<table>
<thead>
<tr>
<th>Design Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Product Modeler</td>
</tr>
<tr>
<td>2. Product Stylist</td>
</tr>
<tr>
<td>3. CAD/CAM</td>
</tr>
<tr>
<td>4. Plastic (Polymer) Product</td>
</tr>
<tr>
<td>5. Detail Design</td>
</tr>
<tr>
<td>6. Electronic &amp; Software</td>
</tr>
<tr>
<td>7. Interface Design</td>
</tr>
<tr>
<td>8. Product Strategy</td>
</tr>
<tr>
<td>9. Industrial Product</td>
</tr>
</tbody>
</table>
End of Questionnaire

The researcher wish to thank you for your time and effort for helping
to ensure this survey a success.
Index 1

Questionnaire V
Department of Design & Technology

Online Survey

Form 2

Research Title:
Towards Establishing an Industrial Design Framework to Support Product Decomposition and Integration Models in Modular Product Development

© Muhammad Firdaus Abong Abdullah
2008
Towards Establishing an Industrial Design Framework to Support Product Decomposition and Integration Models in Modular Product Development

Firdaus Abdullah  m.f.a.abdullah@lboro.ac.uk

Introduction: This questionnaire forms part of PhD research into establishing an industrial design integration framework to support product decomposition and integration models in modular product development. The outcome/results to this questionnaire will be used to support a methodology in developing an initial framework proposal.

Objectives:
1. To identify industrial design needs in modular product design/development based on the perspectives of utility, aesthetics, communication, costs, production and life-cycle.
2. To identify the relative application of industrial design within all phases of modular product design and development.
3. To analyse the factors that justifies the importance of industrial design in modular product design and development.

Terminology
Industrial Design –
The professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer (IDSA).

Modular Product –
A modular product platform definition of modularisation is ‘decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies (Ericsson and Erixon, 1999).

Your details
As one of the selected companies to participate in this research, we would like to thanks you for taking part in our survey. We would be grateful if you could supply some information about yourself to allow classification of your responses. This information will be used solely for this research purposes and will be kept strictly confidential.

Company and address:
Nature of business:
Your name:
Your job title:
Your role and responsibility:

Please proceed (overleaf). Thank you.
Modular Product Design Process
Modularity is a particular design structure, in which parameters and tasks are interdependent within units (module) and independent across them (Clark and Baldwin, 2000). From this definition, one can therefore define that a modular product design process is the method of creating and developing a product that possess a modular structure.

![Modular product design process](image)

In this section, all questions are related to industrial design in modular product design process.

**General**

Your answers on this questionnaire are purely based on your general professional opinion relative to your experiences in the field of product modularity development and industrial design.

9. What products does your company produce?

10. Does your company have an in-house industrial design section/department?
   - [ ] YES  
   - [ ] NO

11. If YES, what is the core function of the section/department in your company?

12. If NO, what is the main reason for not having one?

13. In your own terms, describe a modular product.

14. What is your opinion of product modularity?

15. Do you think your company is producing modular products?
   - [ ] YES  
   - [ ] NO

16. If NO, please specify your product category
**Part 1 – Industrial Design Needs in Modular Product Design**

Please state ✓ either YES or NO for the needs of industrial design services within your modular product design/development process.

<table>
<thead>
<tr>
<th>Industrial Design Service</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Aesthetic and Styling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Utility and Ergonomic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Communication and Corporate identity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Cost Effective Solution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Facilitate Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Product Life-Cycle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part 2 – Anticipated Industrial Design Application Demand**

Please state ✓ either YES or NO for the actual and desired demands of industrial design in your modular product design and development process. The desired demands are based on the next Five (5) Years *Modular Product Design and Development Plan*.

<table>
<thead>
<tr>
<th>Modular Design Task</th>
<th>Actual</th>
<th>Desired</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Product planning/architecture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identifying the need</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigation analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grouping and prioritisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfying customers needs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preparing functional Objectives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identifying operational functions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product/concept generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic functional elements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic physical components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System level specification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identifying SLS impact on GFR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Similarity index and matrix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimisation of element and components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grouping of components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production life-cycle impact</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
End of Questionnaire

The researcher wish to thank you for your time and effort for helping to ensure this survey a success.
Index 2

Interview Survey
Structured Interview Questions

Establishing Industrial Design Framework for (Strategic) Modular Product Development

© Muhammad Firdaus Abong Abdullah 2008
Establishing Industrial Design Framework for (Strategic) Modular Product Development

Firdaus Abdullah, Russell Marshall

Introduction

This interview forms part of a PhD research into establishing an industrial design integration framework to support (strategic) modular product development.

The main purpose of this interview is to find out the industries general perceptions/views towards the (possible)roles of industrial design in their strategic planning of (modular) product development. The secondary purpose of this interview is to find out the industries general perceptions/views towards the (possible)roles of industrial design in their (modular) product planning activity.

The outcome/results to this interview/questionnaire will be used to set up an outline that is necessary to support a methodology in developing an initial framework proposal that forms the principle of this research.

Terminology

1) Industrial Design – Industrial Design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life-cycles (ICSID, 2007).

2) Modular Product – A modular product platform definition of modularisation is ‘decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies (Ericsson and Erixon, 1999).

Part 1 – Your details

We would like to thank you for taking part in our research study. We will need some information about you to obtain more accurate results. This information will be used solely for this research purposes and will be kept strictly confidential.

Company : _______________________________________________________
Nature of business : _________________________________________________
Your name : _______________________________________________________
Your job title : ____________________________________________________
Your role and responsibility : _______________________________________

Please proceed to Part 2, overleaf. Thank you.
Part 2 - Questions

Your answers on this questionnaire are purely based on your general professional opinion relative to your experiences in the field of product modularity development and industrial design.

1 General

1.1 Does your company/organisation have an in-house industrial design section/department? (Please circle one) YES NO

1.2 If YES, what is the core function of the section/department?

1.3 If NO, what is the main reason for not having one?

1.4 In your own terms, describe a modular product.

1.5 What is your opinion on product modularity?

1.6 Do you think your company/organisation is producing modular products?
   YES NO
   If NO, please specify.

2 Product Vision

2.1 Does your company/organisation have an agreed product vision?
   YES NO
2.2 Based on the lists provided, which area should industrial design apply to in relation to an agreed product vision? Please check whichever apply.

<table>
<thead>
<tr>
<th>Vision statement</th>
<th>Product design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product development objectives</td>
<td>Product engineering</td>
</tr>
<tr>
<td>Product development strategy</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Product planning</td>
<td>Human factor/ergonomics</td>
</tr>
<tr>
<td>Product research and development</td>
<td>Aesthetics</td>
</tr>
<tr>
<td>Engineering research and development</td>
<td>Quality assurance and control</td>
</tr>
<tr>
<td>Marketing and marketing research</td>
<td>Component supply chain</td>
</tr>
</tbody>
</table>

Others, please specify: ____________________________

3 Product Planning and Development

![Product Development Strategy diagram](image)

**Figure 1** The refined product planning process (*Baxter, 2002*)
3.1 Does industrial design contribute to the existing process in your current modular product planning and development? YES NO

If NO, please proceed to question 3.8

Based on your process

3.2 How does industrial design contribute in spotting a product opportunity for the current and future market?

3.3 How does industrial design contribute in conducting market research?

3.4 How does industrial design contribute in analysing competing products?

3.5 How does industrial design contribute in proposing a new product?

3.6 How does industrial design contribute in drawing up opportunity specification?

3.7 How does industrial design contribute in drawing up a design specification?

Based on Figure 1

3.8 How should industrial design contribute in spotting a product opportunity for the current and future market?

3.9 How should industrial design contribute in conducting market research?

3.10 How should industrial design contribute in analysing competing products?

3.11 How should industrial design contribute in proposing a new product?

3.12 How should industrial design contribute in drawing up opportunity specification?

3.13 How should industrial design contribute in drawing up a design specification?
4 Product Market Strategy

Terminology

1) **Market dominance strategy** – classified based on the company's market share or dominance of an industry
2) **Innovation strategy** – the company's rate of the new product development and business model innovation, whether the company is on the cutting edge of technology and business innovation
3) **Porter generic strategy** – strategy on the dimensions of strategic scope (market penetration) and strategic strength (sustainable competitive advantage)
4) **Growth strategy** – 'How should the company grow?'; horizontal integration, vertical integration, diversification, intensification

4.1 Which type of strategies does your organisation adopt? Please chose whichever apply: 1 2 3 4

4.2 How should industrial design help in creating a flexible strategy that can respond to changes in customers perception and demand?

4.3 How should industrial design contribute in ensuring the benefit of the product offering to the target market is being communicated?

4.4 How should industrial design contribute in coping with the changing market environment in order to maintain the product success?

5 Product Goal and Measure

5.1 How should industrial design contribute in collecting data and performing measurement in order to create a product goal?

5.2 How should industrial design contribute in creating any visible and defined measures of a product success?

5.3 How should industrial design be involved in planning unique deliverables with identified milestone for a product?

5.4 Should industrial designers be equally responsible for assuring that the product goal is met? (Please circle one)  YES  NO

5.5 If **YES**, how should they contribute?
6  Process
6.1 How should industrial design contribute in creating robust and consistent processes that allow efficient management of product design, development and manufacturing?

6.2 How should industrial design contribute in creating any consistent ways of reviewing the progress of the process?

7  Manpower
7.1 How should industrial designers and other cross-functional teams in the product development group communicate effectively and working together towards a common goal?

7.2 How should industrial designers and other cross-functional teams in the product development group ensure accountability as well as responsibility?

That's all!

Your feedback and time are very much appreciated. Thank you again for your co-operation.
Index 3
Checkpoint
QC & QA Priority Level
Evaluation Form
CHECKPOINT

QC & QA PRIORITY LEVEL

Example

PHASE 1 – PRODUCT DEFINITION

Phase description:

The product planning process takes place before a product development project is formally approved. This is an activity that identifies the portfolio of products to be developed by an organization and the timing of its introduction to the market. It is regularly updated to show changes in the competitive environment, technology, and any relevant information on existing competitive products. The product plans are developed with consideration to the company’s goals, capabilities, and constraints, and competitive environment.

Recommendation:

It is highly recommended that industrial design be applied in specific core activities in this phase in order to have a maximum strategic importance throughout the development process. This standard will emphasize meeting the core task requirements of the product planning phase. The activities within the task requirements are as stated and coded.

In order to determine the relevancy of applying industrial design in this phase, several checkpoints are set. The checkpoints are based on the generic activities that have been identified in each area within the product planning phase.

Important note:

As every product development process involves numerous specific activities within each phase, this standard requires the product development team to map the specific activities into classifications that associate to the generic activities provided in the checkpoints.

1. Checkpoint A – Input

The checkpoint presents the related activities that are required in this phase. The checkpoints also provide the suggested approaches and justifications for implementing
industrial design. The priority level of industrial design application for each activity is determined based on the justification. The details of checkpoint A of product planning are described as follow.

**Check Point A**

**Activity 1**

Classification of modular product development projects

**Code:**

MPD1.1

**Industrial design input**

Provide fundamental and general ideas on the involvement of industrial design in developing the chosen type of project.

**Approach**

Present a general concept of how industrial design values might have optimal impact on the new product in the market.

**Justification**

Industrial design should be present from the initial stage of the product planning to have influential strategic importance. This is considered as one of the first crucial steps as industrial design should be present in defining and standardising component interfaces design specifications in order to access the design and development capabilities within and outside the organisation, which enable a distributed network of industrial designers to develop new components that will be compatible in a new product architecture.
Input priority level

P2 – Significant

Activity 2

Identifying opportunities

Code:

MPD1.2

Industrial design input

Initiate explicit attempt to generate opportunity.

Approach

Gathering ideas for new product or product features by proactively analysing available data on existing products and turning them into new product opportunities. Each promising opportunity should be described briefly and stored in a database, where some of them could be expanded and explored further immediately or in the near future.

Justification

As above (MPD1.1)

Industrial designers are trained to create new innovative ideas for new product development or improvement based on any available data that are relevant to the product.

Input priority level

P2 – Significant
Activity 3

Evaluate and prioritized projects

Code:

MPD1.3

Industrial design input

Assisting a product organisation to select the project with the most potential to be pursued.

Approach

Producing proposals on the appropriate methods or strategies to select a potential project to pursue. There are several methods of evaluating and prioritising project. These proposals are to be discussed at senior management levels.

Justification

As above (MPD1.2)

It is important that the values of industrial design for a potential product be discussed at senior management levels in order to place significant priority.

Input priority level

P3 – Applicable

Activity 4

Allocation of resources and plan timing
**Code:**

MPD1.4  
*Industrial design input*

Assisting product organisation to determine the most promising project to avoid competition for resources.

**Approach**

Producing proposal on the appropriate method or strategy to determine the timing and sequence of each project. This is done to estimate the resources needed for each of the project. For these purpose, a product plan is also proposed.

**Justification**

As above (MPD1.3)  
There are normally several projects that have high potential to pursue, however firms cannot invest in every product development opportunity.

**Input priority level**

P3 – Applicable

**Activity 5**

Complete pre-project planning

**Code:**

MPD1.5  
*Industrial design input*
Involve in producing product vision statements and subsequently the product mission statements;
Involve in establishing the assumption and constraints of the new projects;
Assisting in the appointment of appropriate industrial design staff.

**Approach**

Providing key information especially with regards to the assumptions and constraints that form the product specifications;
Providing key information on industrial design that specifies the values of product human interaction, aesthetics and product differentiation;
Identifying industrial design team members with specialisation in each of the value or both.

**Justification**

As above (MPD1.4)
Industrial designs values must be identify and include in the product specifications;
The industrial design information that forms part of the specification will provide important standard for industrial designer to follow.

**Input priority level**

P2 – Significant

<table>
<thead>
<tr>
<th>Activity</th>
<th>Code</th>
<th>Industrial design Input</th>
<th>Approach</th>
<th>Justification</th>
<th>Priority Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifying opportunities</td>
<td>MPD1.2</td>
<td>Initiate explicit attempt to generate opportunity.</td>
<td>As above (C1.1)</td>
<td>P2</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------</td>
<td>-----------------------------------------------</td>
<td>-----------------</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gathering ideas for new product or product features by proactively analysing available data on existing products and turning them into new product opportunities. Each promising opportunity should be described briefly and stored in a database, where some of them could be expanded and explored further immediately or in the near future.</td>
<td>Industrial designers are trained to create new innovative ideas for new product development or improvement based on any available data that are relevant to the product.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate and prioritized projects</td>
<td>MPD1.3</td>
<td>Assisting a product organization to select the project with the most potential to be pursued.</td>
<td>As above (C1.2)</td>
<td>P3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Producing proposals on the appropriate methods or strategies to select a potential project to pursue. There are several methods of evaluating and prioritising project. These proposals are to be discussed at senior management levels.</td>
<td>It is important that the values of industrial design for a potential product be discussed at senior management levels in order to place significant priority.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allocation of</td>
<td></td>
<td>Assisting product</td>
<td>Producing proposal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is considered as one of the first crucial steps as industrial design should be present in defining and standardizing component interfaces design specifications in order to access the design and development capabilities within and outside the organization, which enable a distributed network of industrial designers to develop new components that will be compatible in a new product architecture.
<table>
<thead>
<tr>
<th>resources and plan timing</th>
<th>MPD1.4</th>
<th>organization to determine the most promising project to avoid competition for resources.</th>
<th>on the appropriate method or strategy to determine the timing and sequence of each project. This is done to estimate the resources needed for each of the project. For these purpose, a product plan is also proposed.</th>
<th>As above (C1.3) There are normally several projects that have high potential to pursue, however firms cannot invest in every product development opportunity.</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete pre-project planning</td>
<td>MPD1.5</td>
<td>Involve in producing product vision statements and subsequently the product mission statements;</td>
<td>Providing key information especially with regards to the assumptions and constraints that form the product specifications;</td>
<td>As above (C1.4) Industrial designs values must be identify and include in the product specifications;</td>
<td>P2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Involve in establishing the assumption and constraints of the new projects;</td>
<td>Providing key information on industrial design that specifies the values of product human interaction, aesthetics and product differentiation;</td>
<td>The industrial design information that forms part of the specification will provide important guideline for industrial designer to follow.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assisting in the appointment of appropriate industrial design staff.</td>
<td>Identifying industrial design team members with specialisation in each of the value or both.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example of completed Checkpoint A form. The details of Checkpoint A show the five (5) activities conducted in Phase 1 of modular product design process.

**Check Point B**

**Activity 1**

Classification of modular product development projects

**Code:**

MPD1.1
Anticipated result

There is a better understanding of the significance of industrial design between the development team for the developed project and resulted in much easier coordination;

The involvement of industrial design throughout the whole development process would be optimised.

Possible non-application consequence

Less understanding of industrial design significant between the development team resulting in difficult coordination and team work;

There would be less involvement of industrial design throughout the whole development process.

Justification

The other development team members have little understanding of the significance of industrial design in the developed project;

The developed project will have minimal industrial design value.

Activity 2

Identifying opportunities

Code:

MPD1.2

Anticipated result

The present of industrial design values formed one of the fundamental essences in the new product strategies, and new product development initiated by industrial designer has high industrial design values.
Possible non-application consequence

The absence of industrial design in new product strategies planning may results in mismatch of resources allocation.

Justification

For industrial design to have maximum impact on the new product, industrial design application has to be planned at the earliest possible stage of product planning. Industrial designers can contribute greatly to making strategic decisions by helping companies to understand the design implication, relative market impacts, and cost benefits of trade-offs that could be made in defining a new modular architecture.

Activity 3

Evaluate and prioritized projects

Code:

MPD1.3

Anticipated result

Industrial design is easily accepted in the new product strategies as the senior management is well inform about its advantages.

Possible non-application consequence

The absence of industrial design in new product strategies planning may results in mismatch of resources allocation.
Justification

For industrial design to have maximum impact on the new product, industrial design application has to be planned at the earliest possible stage of product planning. Industrial designers can contribute greatly to making strategic decisions by helping companies to understand the design implication, relative market impacts, and cost benefits of trade-offs that could be made in defining a new modular architecture.

Activity 4

Allocation of resources and plan timing

Code:

MPD1.4

Anticipated result

There is firm allocation of resources for industrial design.

Possible non-application consequence

There could be minimum or no allocation of resources for industrial design.

Justification

The senior managements would have the perception that industrial design is not a priority in the new product development if industrial design is not represented efficiently and positively.

Activity 5

Complete pre-project planning
Code:

MPD1.5

**Anticipated result**

The present of industrial design values in the vision and mission statements provide a clear application if industrial design within the new project.

**Possible non-application consequence**

Unclear application of industrial design may diminish its values.

**Justification**

The application of industrial design throughout the new project development must be methodically feasible.

<table>
<thead>
<tr>
<th>Activity &amp; Code</th>
<th>Anticipated result</th>
<th>Possible consequence</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification of modular product development projects (MPD1.1)</td>
<td>There is a better understanding of the significant of industrial design between the development team for the developed project and resulted in much easier coordination; The involvement of industrial design throughout the whole development process would be optimised.</td>
<td>Less understanding of industrial design significant between the development team resulting in difficult coordination and team work; There would be less involvement of industrial design throughout the whole development process.</td>
<td>The other development team members have little understanding of the significant of industrial design in the developed project; The developed project will have minimal industrial design value.</td>
</tr>
<tr>
<td>Identifying opportunities (MPD1.2)</td>
<td>The present of industrial design values formed one of the fundamental essences in</td>
<td>The absence of industrial design in new product strategies planning may</td>
<td>For industrial design to have maximum impact on the new product, industrial</td>
</tr>
<tr>
<td>Evaluate and prioritized projects (MPD1.3)</td>
<td>Industrial design is easily accepted in the new product strategies as the senior management is well informed about its advantages.</td>
<td>The absence of industrial design in new product strategies planning may result in mismatch of resources allocation.</td>
<td>For industrial design to have maximum impact on the new product, industrial design application has to be planned at the earliest possible stage of product planning. Industrial designers can contribute greatly to making strategic decisions by helping companies to understand the design implication, relative market impacts, and cost benefits of trade-offs that could be made in defining a new modular architecture.</td>
</tr>
<tr>
<td>Allocation of resources and plan timing (MPD1.4)</td>
<td>There is firm allocation of resources for industrial design.</td>
<td>There could be minimum or no allocation of resources for industrial design.</td>
<td>The senior management would have the perception that industrial design is not a priority in the new product development if industrial design is not represented efficiently and positively.</td>
</tr>
</tbody>
</table>
| Complete pre-project planning (MPD1.5) | The present of industrial design values in the vision and mission statements provide a clear application if unclear application of industrial design may diminish its values. | The application of industrial design throughout the new project development must
An example of completed form for Checkpoint B

**Check point C**

**Activity I**

Classification of modular product development projects

**Code**

MPD1.1

**Coordination / liaison with**

Product owner; potential customers; project manager; project engineer; technical designer; manufacturing organisation.

**Quality control / assurance priority level**

PQ2 – Recommended

**Justification**

Industrial designer good relation with the project team members is important for successful implementation of industrial design idea into the intended project. It is important to provide good understanding of industrial design application and values to all parties involved at the earliest possible phase of product planning.
Activity 2

Identifying opportunities

Code

MPD1.2

Coordination / liaison with

Sales and marketing; research and technology development organisation; manufacturing organisation; current or potential customers; product owners; suppliers; business partners.

Quality control / assurance priority level

PQ2 – Recommended

Justification

Ideas for new products or features can be obtain from these sources and good relationship is vital to maintain smooth exchange of information.

Activity 3

Evaluate and prioritized projects

Code

MPD1.3

Coordination / liaison with
Senior management in sales and marketing; research and technology development; potential customers; business partners.

*Quality control / assurance priority level*

PQ2 – Recommended

*Justification*

It is important that the senior managements are ready and committed to invest in industrial design resources throughout the whole project development stages.

*Activity 4*

Allocation of resources and plan timing.

*Code*

MPD1.4

*Coordination / liaison with*

Senior management in sales and marketing; research and technology development; potential investors and customers; business partners.

*Quality control / assurance priority level*

PQ2 – Recommended

*Justification*

It is important that the senior managements are ready and committed to invest in industrial design resources throughout the whole project development stages.
Activity 5

Complete pre-project planning.

Code

MPD1.5

Coordination / liaison with

Senior management in sales and marketing; research and technology development; potential investors and customers; business partners.

Quality control / assurance priority level

PQ2 – Recommended

Justification

It is important to provide good understanding of industrial design application and values to all parties involved in order to receive full commitment and support throughout the development process.

<table>
<thead>
<tr>
<th>Activity &amp; Code</th>
<th>Coordination/Liaison</th>
<th>QC/QA Priority</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification of modular product development projects (MPD1.1)</td>
<td>Product owner; potential customers; project manager; project engineer; technical designer; manufacturing organisation.</td>
<td>PQ2 – Recommended</td>
<td>Industrial designer good relation with the project team members is important for successful implementation of industrial design idea into the intended project. It is important to provide good understanding of industrial design application and values to all parties involved at the earliest possible phase of product planning.</td>
</tr>
<tr>
<td>Identifying</td>
<td>Sales and marketing;</td>
<td>PQ2 –</td>
<td>Ideas for new products or features can</td>
</tr>
</tbody>
</table>
opportunities
(MPD1.2)

research and technology development organisation; manufacturing organisation; current or potential customers; product owners; suppliers; business partners.

Recommended

be obtain from these sources and good relationship is vital to maintain smooth exchange of information.

Evaluate and prioritized projects
(MPD1.3)

Senior management in sales and marketing; research and technology development; potential customers; business partners.

PQ2 – Recommended

It is important that the senior managements are ready and committed to invest in industrial design resources throughout the whole project development stages.

Allocation of resources and plan timing.
(MPD1.4)

Senior management in sales and marketing; research and technology development; potential investors and customers; business partners.

PQ2 – Recommended

It is important that the senior managements are ready and committed to invest in industrial design resources throughout the whole project development stages.

Complete pre-project planning.
(MPD1.5)

Senior management in sales and marketing; research and technology development; potential investors and customers; business partners.

PQ2 – Recommended

It is important to provide good understanding of industrial design application and values to all parties involved in order to receive full commitment and support throughout the development process.

An example of completed detail elaborations of Checkpoint C form

Verification checklist (Example)

This checklist table is used to verify the relevant of industrial design within each activity of the product planning phase. The objectives of the checklists are as follow:

1. To determine the potential of industrial design application in each development phase.
2. To identify the activities where industrial design is applied.
3. To determine the relevancies of industrial design application within each development phase.
4. To determine the decision to apply or not to apply industrial design within each development phase.
5. To determine the general industrial design priority within each development phase.
The justification results could be used to determine the final decision of considering the feasibility of industrial design in each phase within the modular product development process the company is using.

<table>
<thead>
<tr>
<th>Development phase</th>
<th>Checklist (Standard questions)</th>
<th>Yes</th>
<th>No</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PRODUCT</strong></td>
<td><strong>PLANNING</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Are you currently applying ID in this phase of your product development process? In which activity is ID applied?</td>
<td>(Check)</td>
<td>(Check)</td>
<td>Justifications on why industrial design is applied / not applied in this phase; and description of actual activity where industrial design is applied.</td>
<td></td>
</tr>
<tr>
<td>2. Do you think ID is relevant in this phase of your product development phase? In which activity is ID relevant?</td>
<td>(Check)</td>
<td>(Check)</td>
<td>Justification on the relevancy of industrial design in this phase; and the activity where industrial design is relevant.</td>
<td></td>
</tr>
<tr>
<td>3. Are you planning to apply ID in this phase or some activities of this phase?</td>
<td>(Check)</td>
<td>(Check)</td>
<td>Justification on the industrial design application decision.</td>
<td></td>
</tr>
<tr>
<td>4. What is your general ID priority in this phase?</td>
<td></td>
<td></td>
<td></td>
<td>Suggestion; recommendation; justification on the industrial design priority based on ID priority level (Refer to Section 5.6.4.1)</td>
</tr>
</tbody>
</table>

**Activity & code:**

Classification of modular product development project (MPD1.1)

**Final decision:**

Confirmation of final decisions whether to apply / not to apply industrial design within this phase.

**Justification:**

Justification on the confirmation of decision.

Verification checklist of industrial design application within each phase of modular product design process (Phase 1 – Product planning); this checklist is used repeatedly with the other activities in this phase.
Industrial Design Framework for Modular Product Design (InDFM)

Evaluation form

Note: These evaluation questions are to be used with the “InDFM Evaluation Guideline.”

OBJECTIVE

This document is prepared for users who are implementing InDFM (Industrial design framework for modular product design) trial within their modular product design process. The main objective of the document is to provide a formal structure for evaluating the practicability of the InDFM in meeting the users’ product development requirement.

1 ORGANISATION DETAIL

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>Address</td>
</tr>
<tr>
<td>Nature of business</td>
<td>Firearms and weapon systems manufacturer</td>
</tr>
<tr>
<td>Evaluated department</td>
<td>Product Research and Development</td>
</tr>
<tr>
<td>Evaluator</td>
<td>Evaluator</td>
</tr>
<tr>
<td>Position in organisation</td>
<td>R&amp;D Project Manager</td>
</tr>
</tbody>
</table>

2 FRAMEWORK (InDFM) ELEMENTS

2.1 Users perception on InDFM

2.1.1 As industrial design optimization tool.

<table>
<thead>
<tr>
<th>Useless</th>
<th>Poor</th>
<th>Neutral</th>
<th>Good</th>
<th>Brilliant</th>
</tr>
</thead>
</table>

Comment:

The framework contains a lot of industrial design elements that could be included in the design and development process. The guidelines provided made application of industrial design elements into the design process more understandable. This has made it easier to optimize the industrial design elements in every stage of the product design process.
2.1.2 As industrial design management tool.

<table>
<thead>
<tr>
<th>Useless</th>
<th>Poor</th>
<th>Neutral</th>
<th>Good</th>
<th>Brilliant</th>
</tr>
</thead>
</table>

Comment:

This is particularly useful as the framework provides ways to measure data concerning the application of industrial design; therefore, data management is easier. The timing and scheduling of industrial design process is clearly understood.

2.1.3 Enhancement of product design process.

<table>
<thead>
<tr>
<th>Useless</th>
<th>Poor</th>
<th>Neutral</th>
<th>Good</th>
<th>Brilliant</th>
</tr>
</thead>
</table>

Comment:

Product design process varies on different product requirements, so is the need for industrial design. The framework does not necessarily complete the process, but by having and knowing the potential of industrial design in each stage provides an advantage for developers to quickly meet the needs if required.

2.1.4 Supporting collection and transmission of industrial design requirement data.

<table>
<thead>
<tr>
<th>Useless</th>
<th>Poor</th>
<th>Neutral</th>
<th>Good</th>
<th>Brilliant</th>
</tr>
</thead>
</table>

Comment:

By knowing the industrial design needs in each of the design process phases, collection of important and critical data needed can be identified. For example, data on human variance anthropometrics could be used by industrial designers and engineers to optimize the product user interactions on several different phases of the design process.

2.2 Feasibility of InDFM process

2.2.1 Mapping process by InDFM codes.

<table>
<thead>
<tr>
<th>Difficult</th>
<th>Neutral</th>
<th>Easy</th>
</tr>
</thead>
</table>

Comment:

This is a large amount of work as thorough discussion needs to be done, but the whole process is quite easy and straightforward.

2.2.2 Setting objectives by InDFM codes.

<table>
<thead>
<tr>
<th>Difficult</th>
<th>Neutral</th>
<th>Easy</th>
</tr>
</thead>
</table>

Comment:

The process is helped by the use of the code index, although in the future, a computer tool with improved interface could be better.
2.

<table>
<thead>
<tr>
<th>Difficult</th>
<th>Neutral</th>
<th>Easy</th>
</tr>
</thead>
</table>

Comment:

This also involved a large amount of work but the discussion is assisted by the use of technical guideline.

2.2.4 Mapping industrial design critical dimension to specific tasks in each phase of modular product design process.

<table>
<thead>
<tr>
<th>Difficult</th>
<th>Neutral</th>
<th>Easy</th>
</tr>
</thead>
</table>

Comment:

Need thorough discussion and large amount of job but the task is easily accomplished.

2.2.5 Structuring new product design process with InDFM.

<table>
<thead>
<tr>
<th>Difficult</th>
<th>Neutral</th>
<th>Easy</th>
</tr>
</thead>
</table>

Comment:

As mentioned earlier, developing and structuring a new product design process varies with different product. Some of our products are very complex and thus needing more processes than the others. Adding the InDFM into the complex process is challenging but achievable.

2.2.6 Adapting and synchronizing InDFM process into existing/conceptual modular product design process.

<table>
<thead>
<tr>
<th>Difficult</th>
<th>Neutral</th>
<th>Easy</th>
</tr>
</thead>
</table>

Comment:

It would be easier on the conceptual process compare to the existing one. Adapting the framework to the existing process may leads to adding more requirements into the product specification.

3 InDFM IMPLEMENTATION

3.1 Retrospective implementation

3.1.1 Optimized industrial design application in the existing modular product design process.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

This is some kind of hype at the moment since the company is focusing on a very large program of process. The management and development department are very careful, a new process that involve two different development aspects like modularity and industrial design is difficult to achieve in the environment as they
are not a priority. The introduction of a new process midway may lead to putting additional requirements into the product specification, and this should be done without compromising its performance. Performance is always the priority, modularity and industrial design is something in the background.

3.1.2 Improved industrial design application in existing modular product design process.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

The technology of the product is so mature that it is difficult to increase the performance that much. Because of this I would like to point out that we should look at the differentiator. Since the performance is very difficult to improve because the technology is so mature than we have to go into different area to improve, and two major points that we could improve is fact is modularity and industrial design. Industrial design could provide the differentiator factors that are needed to put us in better position than our competitors, unless we have another cartridge to go with the 5.7mm.

3.1.3 Better/increase understanding of industrial design needs within each stage of the existing modular product design process.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

The new framework has provides better understanding of how industrial design contributes to the whole process. It is difficult to convince the marketing with just words of mouth. The marketing department is saying that the design of our less lethal applicator is too bulky like the 'old style Russian things'. They are suggesting that we should develop some kind of a distinction design that would directly point out all the facts that the applicator is less lethal. This is a difficult task because we are more or less link to the technology and the way we are using it. With the framework, we could see clearly how and where industrial design is needed in each stage of the development process.

3.1.4 Enhanced overall design process through innovative and creative design and problem solving approaches.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

Innovation is one aspect that we have as you have seen some quite innovative design we have made for the F2000 and the P90. Unfortunately they are not really well received, depending of course on different kind of market. It was quite disappointing although we tried to be innovative, they were not well received. Customers want something conventional. But perhaps there could be potential for a more emerging market like for the less lethal application. This new framework could work on external improvement of the same design but for application wise
the internal mechanism need some minor engineering changes which I think is less feasible with the new framework.

3.1.5 Improved product in term of functionality, performance and appearance.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

In firearms design, the designs need to look threatening. We are facing difficulties in designing the less lethal applicator as the fact that it must be seen as threatening but at the same time not too threatening because it is recognize as something less lethal. For example, ‘ok we will not shoot you with a gun’ – that is a very difficult design approach. The framework has provided us with the idea and method on how to do this. Probably not so much on functionality and performance factors but surely on the appearance. The existing process was developed with performance in mind.

3.2 Conceptual implementation

3.2.1 Optimized industrial design application in the conceptual modular product design process.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

As mentioned, the management and development department are very careful, developing a new process with additional aspects, modularity and industrial design will add some new tasks into the environment. However, as it is a new process, it is worth considering, not necessary to complete the process but something we should have in mind or taking into account. The application of industrial design could help us increased the performance of our product, not on the firepower but on users interaction and ergonomics. The framework provides industrial design of new components and configuration of components that could lead to improved user interaction and ergonomics.

3.2.2 Improved industrial design application in conceptual modular product design process.

<table>
<thead>
<tr>
<th>Not at all</th>
<th>No</th>
<th>Possibly</th>
<th>Yes</th>
<th>Very much</th>
</tr>
</thead>
</table>

Comment:

Certainly, the framework provides ways to improved industrial design of the product. It is easier to include this factor in new process. In dealing with military, it is utility, maintenance and cost. That should be the emphasis of industrial design in the new process. Utility criteria could be obtained from the users, which make it an interesting task.

3.2.3 Better/increase understanding of industrial design needs within each stage of the conceptual modular product design process.
Our process of design and development is very long and painful, and of course on six month time from our point of view is nothing. There are a lot of stages involved in our process and some of them may look like they don’t need any industrial design, but the framework has changed our understanding that it is not necessary to totally involve industrial design in the entire process but providing ideas on useful creative and practical solutions at relevant stages. With this we are able to say that that part should be improved. As we are looking into a number of users driven product, the new process is useful especially at the initial stage, and for some products we are still in the concept development phase. This has really provided some guidance.

3.2.4 Enhanced overall design process through innovative and creative design and problem solving approaches.

As we never did functional analysis on our existing product because the concept is so fixed, it has been totally ignored. If we are given a project to develop a new rifle, everybody knows what a rifle is and its functionalities. Functionality is already there in the background. This is actually a disadvantage because if we continue with that kind of reasoning we will never be innovative. The new framework has change our perception as functional analysis could also be done on other factors. The framework has given us the belief that innovation can be related to new functionalities, new ways to work and articulate the functionalities.

3.2.5 Improved product in term of functionality, performance and appearance.

We are toying with a new concept which we term ‘armatronic’. This is something really conceptual and new. The new concept will certainly involve new approaches in meeting the functionalities, performance and appearance requirements. The new concept is a combination of armament and electronics which will involve a lot of different technology. The new concept will also need industrial design solution to meet the functionality, performance and appearance of the new product. At the moment we are working on how to tackle the issues of managing product variants. This new product will add more variants. The use of the framework may also help us characterized our variants.
4 EVALUATION SUMMARY

Overall, the new framework (InDFM) has achieved its intended purpose of optimizing industrial design potential in modular product design process. The framework has demonstrated that it has managed to meet the development specifications as we have found out that the framework has good to optimize industrial design.

<table>
<thead>
<tr>
<th>Evaluators signature</th>
<th>Signed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researchers signature</td>
<td>Signed</td>
</tr>
<tr>
<td>Date</td>
<td>January 2010</td>
</tr>
</tbody>
</table>

Copyrights © M.F.A.Abdullah 2010
Index 4

Product Development Process Reference
**Description of processes**

**DEVELOPMENT – INDUSTRIALISATION**

Complete the design, development and industrialization of products according to market needs expressed by the Marketing in the optical 'system-weapon-munition' and respect for objectivity, quality and limit

**Ressources:**
- Head of project RDI – Product Manager MKT
- Designers
- Designers - Matters in point
- Testing Centre - Workshops proto / Mechanical
- Production entities - Subcontractors
- Tool CAD, PDM (Product Data Management)

**Reference:**
- MAQ 7.3.0 – 7.5.0
- PRQ 04.010 à 04.160
- PRQ 06.000
- PRQ 07.070

**Entrees:**
- Business plans
- Technical specifications (yc. legal requirements / regulations applicable to the project)
- Planning for the design, development, industrialization
- Decisions from the management of development projects

**Activities:**
1. **Design**
   - Study design
   - Tests, developed and evaluations
   - Estimation costs, risk assessment
   - Critical Design Review
2. **Development**
   - Development study
   - Tests, developed and evaluations
   - Establishment of technical definition file
   - Qualification of development
3. **Industrialization**
   - Establishment of Manufacturing Folder / Control
   - Developed processes, testing
   - Keeping records of quality requirements
   - Qualification of industrialization

**Documentation:**
- Quality Standards (NOQ)
- National standards, international
- Data from previous studies

**INDICATORS:**
- QA indicator development
- QA Indicator industrialization
- Monitoring of project expenditure
- Monitoring of progress

**Outputs:**
- Planning for the design, development, industrialization updates
- Business Plan / Specifications updated technical
- Definition file Technique (DDT) available
- Kit Manufacturing and Control (DFC) available
- File qualitative requirements (DEQ) available
- Technical data of the products available in CAM and PDM
- Machinery manufacturing and control available
- Operating range available in GPAO
- Current production authorized
Operation Processes
Design, development, industrialisation

1. Launch design phase following a review of preliminary analysis, cf. PRQ 02000
   - 1. Debut

2. Complete design, Alternatives

3a. Manufacturing design, alternatives
   - 3a. Pieces produced prototypes
       - 3a. Record results

3b. If necessary, request acquisition of prototype parts
   - 3b. Manual Requisition (Request for purchase or supply) and definition to Shopping

3c. Order prototypes pieces
   - 3c. Pieces produced prototypes

3d. Receive prototype pieces purchased
   - 3d. Record results

4. Assemble first working prototype
   - 4. First working prototype available

5. Establish program evaluation
   - 5. Evaluation program established

Legend:
- Pilot action
- Participants involved
6. Perform tests, developed & evaluate the first prototype

7. Preliminary review

8. Examine initial technological options

9. Estimate cost of producing, production, investment

10. Continue project planning

11. Realising Critical Design Review (CDR)

12. Decide whether the CDR, update Business Plan and / or technical specifications

13. Launch phase of development

14. Realising studies, developed, development analysis, configuration choices

15. Decider of industrial investment

6. Results of testing, evaluation recorded

7. Journal Reports
   Acceptable design - 8
   Refuses design - collective or selective reiteration

8. Technological options determined

9. Estimated costs

10. Planning (time-event) reviewed

11. Report Review
   Acceptable design - 12
   Design refused - collective or selective reiteration

12. Business Plan / CaCh Technique updated

13. Development phase launched

14. Dossier studies (results of calculations and tests)
   Fixed configuration
   Assessed risk

15. ‘Make or Buy’ decide
16. Gradually established DDT based technologies contemplated and 'Make or Buy'

17. Prepare pre-industrialization parallel

18a. Realise pieces technological prototypes

18b. If necessary, request acquiring pieces technological prototypes

18c. Order pieces prototype technology

18d. Receive pieces technological prototypes

19. Assemble functional prototype technology

20. Establish program evaluation

21. Perform tests, developed prototypes and evaluations

22. Realise intermediate review
23. Initiate File qualitative requirement (DEQ)

24. Develop qualification program development, cf. PRQ 04020

25. Approve Qualification Program development

26. Run the following qualifying events program, cf. PRQ 04020

27. Review Achieve Qualification Development, cf. PRQ 04020

28. Launch phase of industrialization

29. File Finalised Manufacturing / Control (DFC)

30. Initiate micro-process

31. Making the manufacturing process and control

32. Finaliser Dossier d'Exigences Qualitatives (DEQ)

23. Draft DEQ established

24. Qualification Program development established

25. * Program approved → 26
   * Program refused → 24

26. Results of qualification tests recorded

27. * qualification certificate issued, cf. PRQ 04020
   * QA Development determined, cf. PRQ 01420
   * Qualification granted → 28
   * Qualification refused reiteration → collective or selective

28. Industrialization phase launched

29. DFC fixed, and cf. PRQ 04040 04070

30. Micro-process available

31. Means of production and control available

32. DEQ intranet available, cf. PRQ 04090
33. If applicable, train and qualify operators for special processes, cf. PRQ 07070
34. Achieving development of manufacturing processes of components
35. Establish operating ranges
36. Manufacture pilot lots or pre components (cf. PRQ 06000 lots for acquisition pilots externally)
37. Assess manufacturing process
38. If necessary, perform corrective actions and update technical files accordingly
39. Making testing assembly
40. Assemble pilot batches produced
41. Evaluating assembly process
42. If necessary, perform corrective actions and update technical files accordingly

33. Operators trained and qualified to special processes
34. Manufacturing processes of the components developed
35. Operating ranges available tool GPAO
36. Pilot batches available components
37. * Report on pilot batches produced components
   * Request for possible corrective actions issued
38. * Corrective actions undertaken
   * DDT, DFC, DEQ updated
   * File updated definition of justification
39. * successful tests → 40
   * Tests stranded → 34
40. Pilot batches product available
41. * Report on pilot batches realized
   * Request for possible corrective actions issued
42. * Corrective actions undertaken
   * DDT, DFC, DEQ updated
   * File updated definition of justification
7.2 Modification

Any changes must be communicated in writing (notes, reports, minutes of the meeting ...) in charge of the technical document to be amended, in describing and explaining the reason for the proposed amendment.

The actions necessary to amend the design and development involve the same actors as those involved in the process of design and initial development of products whose provisions are also applicable.

At magazines, special attention is given to evaluating the impact of changes on the components of the product and the product already delivered.
Index 5

Survey Presentation
Establishing industrial design framework to support product decomposition and integration models in modular product development

Firdaus Abdullah
19 March, 2009
Presentation overview

- Introduction
- The research
- Proposed framework
- Research collaboration
- Benefit
- Key issue
Introduction

Firdaus Abdullah, industrial designer & researcher based in Malaysia.

Currently studying for a PhD at Loughborough University, UK.

Research scope:
Industrial design in modular product design and development process
Introduction

*Loughborough University*

Loughborough University is world renowned for the high calibre of research it produces.

University of the year 2008-2009 (*Sunday Times Award*).

*Design Technology Department*

Top rated in the United Kingdom (*Research Assessment Exercise, 2008*).
Introduction

Visit our web site: http://www.lboro.ac.uk
Definition

*Modular product* – A product created by the integration of building blocks (modules) with specified interfaces to achieve its intended function, driven by company-specific strategies (*Ericsson and Erixon, 1999*).
**Definition**

*Industrial design* – The professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer *(IDSA, 2009).*
Definition

*Modular system development* – A stage that primarily involved product or concept analysis and integration in modular product development process.
Common goals

*Industrial design*

- Utility
- Appearance
- Ease of maintenance
- Low cost
- Communication *(Dreyfuss, 1967)*

*Modularity*

- Greater product variety
- Faster technological upgrading
- Greater speed in producing new model
- Cost reductions *(Sanchez, 2002)*
The research

Aim

Develop an industrial design integration framework that supports the modular system development in modular product development.

Objectives

Investigate and assess the industrial design of product decomposition and integration models in modular product development.

To promote the practicability of industrial design to modular system development in modular product development process.

To support continuous modular product development and improvement through optimisation of industrial design.
Initial investigation

Methodology

Literature review and empirical investigation.

Investigation factor

Perceived importance of industrial design functions in product development process;

Strategic industrial designer’s role in modular PDP;

Involvement of industrial designers in modular PDP.
Initial investigation

*Scope of investigation*

Companies and organisations located in the midland and southern region of the United Kingdom.

*Product categories*

Simple product
Mechanically complicated product
Heavy industrial product
Advanced technology product
Investigation result

Generic product development process

Fig. 1 Relative timing of industrial design in product development process
Investigation result

Modular product development process

Planning

Concept development

• Generate alternative product architecture (optimisation models)
• Define major sub-systems and interfaces
• Core research investigation area
• Overall research investigation area
• Refine industrial design

System-level design

Detail design

• Define parts geometry
• Choose materials
• Assign tolerances
• Complete industrial design control documentation

Testing & refinement

Production ramp-up

Modular systems development stage

Industrial design processes

Technology-driven products

User-driven products

Fig. 2  Relative timing of industrial design in modular product development process
Fig. 2  Relative timing of industrial design in modular product development process
Argument

Why is industrial design partially applied in the modular product development process?

What are the impacts toward modular system development if its potentials are optimised throughout the entire process?

Can its application actually support the process?

What are the values received if industrial design is used all the way throughout the process?
Rationale – a success story

Example - company’s strategy

Apple computers and electronics
Research progress

*Current stage (final data collection) of the PhD research:*-

- Validation of proposed framework model. *(on-going)*

- Initiate research co-operation with potential partner/s. *(on-going)*

- Trial and evaluation of proposed framework on case studies of actual MPD process. *(planned)*

- Record and analysis of data from the case study. *(planned)*
Fig. 4  Domain of ID critical goals contributions in generic modular product development structure.
Proposed framework

*Specifications*

Provide a method to optimise the potential of industrial design benefits in modular product design and development with emphasis on modular system development.

Enable the enhancement of the currently used process through the addition of a clearly defined structure containing new design and development elements.

Contain industrial design management capability to optimise the potential of industrial design in modular system development.

Able to be integrate and adjust into the existing process.
Proposed framework

Fig. 5 Industrial design framework for modular system development
Proposed framework

Industrial design input
1. Utility
2. Appearance
3. Communication
4. Ease of maintenance
5. Cost consideration

Fig. 6 Industrial design framework for product/concept analysis
**Proposed framework**

---

**System decomposing**

- **Modular system development**
  - **Industrial design input**
    1. Utility
    2. Appearance
    3. Communication
    4. Ease of maintenance
    5. Cost consideration

---

**Fig. 7** Industrial design framework for product/concept integration

---

**Industrial design input**

1. Utility
2. Appearance
3. Communication
4. Ease of maintenance
5. Cost consideration

---

**Modular system**

- **System level specification**
  - **Physical characteristic**
  - **Functional characteristic**

---

**System decomposing**

- **Impact analysis**
  - **Similarity index**
    - **Similarity matrix**
      - **Optimisation model**
        - **Modules/Sub-system**

---

**General function requirement**

1. Utility
2. Appearance
3. Communication
4. Ease of maintenance
5. Cost consideration

---

**Modular system development**

- **Industrial design input**
  - 1. Utility
  - 2. Appearance
  - 3. Communication
  - 4. Ease of maintenance
  - 5. Cost consideration
Proposed framework

**Fig. 8** Industrial design framework for modular system development
Research collaboration

The collaboration is between:

Firdaus Abdullah, PhD research student,
Dr. Russell Marshall, research supervisor,
Dr. Ian Campbell, director of research,
Department of Design Technology, Loughborough University,
United Kingdom.

&

Research and development department,
FN Herstal, Liège,
Belgium.
Aim & objective of collaboration

To seek technical assistance to support the research – The assistance need is in the form of information on R&D process.

To observe existing process in real life setting - To investigate and record the industrial design of modular system development in actual modular product development process.

Discussion and talk to personnel involve - To Exchange information and knowledge in the research area to ensure continuous product development and improvement.

Possible case study - Introduce and assess a new approach (based on a framework) in a real life modular product project.
Benefit

To FN Herstal:

To achieve broader perspective in the re-evaluation process of the current PDP with inputs from academic resources.

Opportunity to co-operate in future new product design and development with emphasis on product modularity.

Opportunity to exchange information and knowledge in the field of product modularity for continuous product improvement.

Creating richer varieties of acceptable new products in competitive product environment with assistance from academic partner.
Benefit

To the researcher:

To acquire an actual and real time result of the proposed framework.

Provide a comprehensive understanding of advantages and limitations in the application of the proposed framework to an actual process.

Provide experience and upfront knowledge for further investigation of the framework in other characteristics of modular product.

To produce academic publications and PhD thesis that are produced from experimenting on actual and real world application.
Benefit of framework

Potential benefits of the integration framework to FN Herstal

Optimisation of industrial design in existing process in order to produce greater and better product variants.

Greater speed and flexibility in developing new products.

Faster and economical upgrading of technology for products including the existing products.
Approach

Data collection

Identifying investigation areas in relation to the research. (on-going)

Identifying relevant personnel in investigation areas to be involve in the research. (on-going)

Investigating the current design and development methodology in relation to the research. (on-going)

Identifying the design and development activities involved in the currently applied PDP. (on-going)
Approach

Evaluation

Identifying and evaluating the actual roles of industrial designers in the PDP currently applied. *(on-going)*

Identifying and evaluating the interaction of industrial designers and the cross-functional team members in the PDP currently applied. *(on-going)*

Application

Applying new design and development methodology into the PDP through the introduction of framework. *(on-going)*
Approach

*Reporting and feedback*

Assessing and identifying opportunities for improvement of the new framework. *(on-going)*

Documenting the results of the trial and assessment. *(on-going)*
Key issues

Proprietary information

Thesis and publication

To have further discussion with FN Herstal.
End of presentation

Thank you
Index 6

Article 1

INTERNATIONAL DESIGN CONFERENCE – DESIGN 2010

Dubrovnik – Croatia, May 17 – 20, 2010
A RESEARCH OVERVIEW OF INDUSTRIAL DESIGN FRAMEWORK FOR MODULAR PRODUCT DESIGN

M. F. A. Abdullah, R. Marshall

Keywords: Industrial design, Modular product design, Design process, Design process application framework

1. Introduction

This research paper concerns industrial design and its potential to support design and development needs in product modularisation. The aim of the research is to develop a systemic approach to optimise industrial design prospects in modular product design through the application of a new framework known as InDFM (Industrial Design Framework for Modular Product Design/Development). The hypothesis is that product design and development organisations have failed to take full advantages of this prospect, taking an ad hoc or localised approach to industrial design within their modular product development process. The application of InDFM is supported by a defined and comprehensive technical guideline document that is essential for successful application of the framework. InDFM is the outcome of PhD research being conducted at Loughborough University in the UK that currently in its final development stage. Once fully developed the framework will undergo validation with a number of European based companies.

2. Motivations and reviews

A shift in competitive environment has forced many companies to diversify from the standard mass-market products into variations of similar products or mass-customisation (Kratochvil and Carson, 2005). Thus, the concept of modularity (Sanchez, 2002; Baldwin and Clark, 2000; Kamrani and Salhieh, 2000; Ericsson and Erixon, 1999) was introduced. Growing numbers of global product companies are now not only adopting modularity, but are also adopting new kinds of product strategies and implementing new development processes that are explicitly focused on achieving a range of competitive advantages through modular product design (Sanches, 1999). However, a review of literature in the area shows that current approaches to modularity are largely the domain of engineers and technical designers and there is little to suggest that the potential role of industrial design within modularity is recognised. Therefore, it is assumed that researchers and product organisations have failed to perceive the strategic importance of the industrial designer within the modular product design process. It is also assumed that in many product development processes, industrial design has rarely been described as an important element that contributes to the strategic planning programs of a product focused organisation.
The industrial mainstream tends to perceive industrial design as a source of aesthetics and rarely as a major contributor to the sales proposition (Desbarats, 1994). In reality, industrial design provides critical visual and tactile elements which are the ultimate influencers both on immediate sales and on total customer experience over a product’s lifetime. The influence of industrial design is unrestricted as industrial design services can be applied to most industries (Ulrich and Eppinger, 2000). These concerns ultimately are the goals that prompted the importance of industrial design, which imperatively should be fully exploited throughout the process of modular product design.

Figure 1. Philips electric shaver series (Philips Electronics, 2010)

An example of a successful application of industrial design in modular product design is highlighted by Philips Electronics with its series of electric shavers (Refer to Figure 1). The company has demonstrated in this product family that industrial design played a critical role in providing spatial styling variations while maintaining the same degree of user interaction and ergonomics. Industrial design in products such as illustrated provides some of the few critical differentiators in developing compelling, and globally competitive brand propositions (Juratovac, 2005; Mostowics and Grzecznowska, 2004; Desbarats, 1994).

3. Proposed research

The issue of industrial design’s underutilised potential has prompted research into a dedicated framework and systemic approach to utilise the full potential of industrial design in a modular product design process.

The initial investigation of this research has indicated that there is a growing need to develop approaches to integrate and optimise industrial design in modular technical design as a growing number of global companies now adopt modularity concepts in managing the technical development of their new products. This is supported by an article from Sanchez and Collins (2001), that firmly states industrial design as one of the most important strategic tools in developing modular products. The strategic importance includes 1) The need to develop design concepts for more extensive product lines in order to increase product variety. 2) Refreshing product designs through styling changes in visible components for technologically mature modular products. 3) An essential role in modular product strategies
by creating styling variations that can effectively distinguish individual product models within a modular product family. 4) Helping to bring a series of technologically upgraded products to market in rapid succession. 5) Providing effective differentiation of new product models by stylization in order to communicate visually the improved technical performance of the new product.

The research approach began with reviews of industrial design processes in order to fully understand the generic process and its intended goals. Emphasis is made on the perceived importance of industrial design functions, including strategic inputs and key roles in standard product design and development processes across a broad range of industries. In addition to industrial design, the modularity concept and the relevant processes of modular product design and development were also reviewed. Both reviews are conducted to identify the appropriate method within each domain. Other qualitative research methods particularly questionnaire surveys and interviews were also conducted with selected British and European companies that are involved in developing and manufacturing modular products, for the purpose of identifying when and where industrial design is being utilised in their design processes. The results from the initial investigation (Refer to Figure 2) showed that the senior management of the companies surveyed rated industrial design as applicable in their design process but with substantial deliberation. This result forms part of the basis to develop a new industrial design framework with associated technical guideline documents to facilitate the optimisation of industrial design in modular product design.

This paper provides an overview of the proposed framework which includes the mechanism of the framework, the components of the mechanism, and the application representation of the framework. This paper will be concluded with suggestions for future work.

![Figure 2. Application rating of industrial design in strategic product planning (Abdullah, 2008)](image-url)
4. Integrated process

The discipline of industrial design itself cannot contribute its full potential as a strategic planning tool unless it is integrated in the product design process. In order to do this, industrial designers need to be involved throughout the process as this is the best way to maximize the value that industrial design can bring to the finished product. This is especially crucial for a product with a high degree of user interaction and the need for aesthetic appeal. The other specialists in the multi-skilled teams will need to collaborate with the industrial designer to ensure the successful execution of an industrial design approach. The complete involvement of the industrial designer forms the basis to integrate industrial design formally as part of a new product design process and to provide a coherent strategy for the new process itself.

4.1. Industrial and modular design process

Generically, the process of industrial design involves six stages that begin with 1) Investigation of customer needs. 2) Conceptualisation of a design. 3) Preliminary refinement of a design. 4) Final concept selection of a design. 5) Production of control drawings. 6) Coordination with other relevant members who are involved in the project. For each stage of the process, emphasis is given to achieve the ultimate goals of satisfying both the manufacturer and consumer needs by constantly considering the industrial design critical dimensions. To assess the importance of industrial design in any product design processes, the researcher has identified five critical dimensions (Refer to Figure 3) that need to be achieved for any product to be considered successful in an industrial design context. These dimensions are then characterised into sub-dimensions, which describe the objectives of each dimension.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utilities</strong></td>
<td>• Ease of use</td>
</tr>
<tr>
<td></td>
<td>• Ease of maintenance</td>
</tr>
<tr>
<td></td>
<td>• Quality and quantity of interaction</td>
</tr>
<tr>
<td></td>
<td>• Safety</td>
</tr>
<tr>
<td></td>
<td>• Novelty of interaction</td>
</tr>
<tr>
<td><strong>Aesthetics</strong></td>
<td>• Product differentiation</td>
</tr>
<tr>
<td></td>
<td>• Pride of ownership, image, fashion</td>
</tr>
<tr>
<td></td>
<td>• Communication</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>• Cost benefits and trade-offs</td>
</tr>
<tr>
<td></td>
<td>• Appropriate usage of resources</td>
</tr>
<tr>
<td><strong>Production</strong></td>
<td>• Manufacture and assembly</td>
</tr>
<tr>
<td></td>
<td>• Appropriate usage of raw materials</td>
</tr>
<tr>
<td></td>
<td>• Tooling</td>
</tr>
<tr>
<td></td>
<td>• Packaging</td>
</tr>
<tr>
<td><strong>Product life-cycle</strong></td>
<td>• Life-cycle design</td>
</tr>
<tr>
<td></td>
<td>• Material selection</td>
</tr>
</tbody>
</table>

Figure 3. Industrial design critical dimensions (Adopted from Dreyfuss, 1967)
Modularity is an approach familiar to most designers. It is a powerful design strategy, which is now becoming an integral part of mainstream strategic management thinking (Sanchez, 2002). To develop a complex product using the modularity concept, a three-phase methodology would normally be applied (Kamrani, 1997). Design for modularity (Refer to Figure 4) provides several classifications (Kamrani and Salhieh, 2000) which include 1) Product and problem decomposition. 2) Structural and modular decomposition. 3) Analysis between components and specifications. 4) Application of group technology classification system. 5) Measure matrix construction. 6) Module selection optimization.

Figure 4. Overview of modular product design process (Adopted from Kamrani and Salhieh, 2000)

4.2. Industrial design in modularity

There is an essential need to develop approaches to apply industrial design in modular product design and several important strategic objectives for industrial design in modularity have been identified. Currently there is a lack of a systemic implementation approach. The common approach adopted by most product organisations is engaging industrial designers with engineers or technical designers as a visual and tactile element specialist mainly to provide aesthetics and human factor values to the product being developed. The approach is generally ad-hoc or localised resulting in an inconsistently managed process without a defined methodology that optimises industrial design’s full potential and the designer’s capability. The next section will describe the proposed framework for industrial design to support modular product design processes.
4.3. Introduction to InDFM

The aim of InDFM is to provide a systemic method for managing industrial design implementation in modular product design and development. This framework then provides a means to optimise the potential benefits of industrial design that could be applied to both new and existing processes. This will in turn provide greater speed and flexibility in developing new products in addition to supporting faster and economical upgrading of technology for existing products. The final outcome of the application is the production of greater and improved product variants. The specifications of the framework include 1) Provide a method to optimise the potential of industrial design benefits in modular product design and development. 2) Enable the enhancement of the currently used process through the addition of a clearly defined structure containing new design and development elements. 3) Contain an industrial design management capability to optimise the capability of industrial designers in modular design and development. 4) Support collection, management (analyse, select, verify) and transmission of information and data on industrial design requirements. These specifications support application to any modular design and development processes and are flexible to adapt to any changes within the used modular design and development process stage.

4.3.1. Mechanism of InDFM

The InDMF consists of a clearly defined structure (Refer to Figure 5) containing industrial design critical dimensions (CD), which encompass the objective elements of industrial design functions within a generic industrial design (ID) process, a new modular product design and development process, an existing modular product design and development process, and the applied modular product design and development (MPD) process.

![Figure 5. Mechanism of InDFM](image)

To apply the InDFM into a new process, the design team is required to map the activities within the process to the critical dimensions. The mapping is essential as every product development process involves numerous specific activities within each phase that correlate to the critical dimensions and the ID process. The design team need to group the
activities into classifications in relation to industrial design processes that could be adopted into the generic tasks within each phase of the new process. For an existing process, the classified activities are incorporated into the generic tasks within each phase. Once all the industrial design elements are established in the processes, the processes can now be used with consistent quality assurance monitoring to ensure efficient management of related resources and timing.

4.3.2. Structure of InDFM

The process of structuring the framework begins by using the industrial design critical dimensions to assess the industrial design requirements in a proposed modular product. The basis of the investigation is justifying each sub-dimension (for example – Ease of use) against the generic intended functions of the modular product (for example – Inputting a journey into a satellite navigation system). The justification task is critical to determine the priority classifications of each sub-dimension within the modular product functions. The classification results are analysed and then used to specify sets of objectives (Refer to Figure 6) in relation to each phase of the industrial design process. Each stage of the industrial design process is then applied to a modular product design process, where the actual requirements of industrial design are needed. There is a tendency that several industrial design processes may apply to some modular product design phases (Refer to Figure 7, 8). This is because these phases, such as concept generation, and decomposition of functional and physical elements (Refer to Figure 7, 8) require several industrial design processes to be carried out for the phases to achieve its intended function. The integrated processes of industrial design and modular product design is then either adopted as a new process, or incorporate into an existing process.

![Figure 6. Example of objectives sets for phase 2 of modular product design](image)
Figure 7. The structure of InDFM; Please refer to Table 1 for the numbering codes

<table>
<thead>
<tr>
<th>Modular Product Development</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD1</td>
<td>Project definition</td>
</tr>
<tr>
<td>MPD2</td>
<td>Customer needs analysis</td>
</tr>
<tr>
<td>MPD2.1</td>
<td>Identifying needs</td>
</tr>
<tr>
<td>MPD2.2</td>
<td>Analysis approaches</td>
</tr>
<tr>
<td>MPD2.3</td>
<td>Needs grouping and prioritisation</td>
</tr>
<tr>
<td>MPD2.4</td>
<td>Satisfying customer needs</td>
</tr>
<tr>
<td>MPD3</td>
<td>Product requirement analysis</td>
</tr>
<tr>
<td>MPD3.1</td>
<td>Customer needs results application</td>
</tr>
<tr>
<td>MPD3.2</td>
<td>Weighing general function requirement</td>
</tr>
<tr>
<td>MPD4</td>
<td>Product/Concept analysis</td>
</tr>
<tr>
<td>MPD4.1</td>
<td>Product/Concept generation</td>
</tr>
<tr>
<td>MPD4.2</td>
<td>Decomposition – functional elements</td>
</tr>
<tr>
<td>MPD4.3</td>
<td>Decomposition – physical elements</td>
</tr>
<tr>
<td>MPD5</td>
<td>Product/Concept integration</td>
</tr>
<tr>
<td>MPD5.1</td>
<td>System level specification (SLS)</td>
</tr>
<tr>
<td>MPD5.2</td>
<td>Identification of SLS impact on GFR</td>
</tr>
<tr>
<td>MPD5.3</td>
<td>Providing similarity index and matrix</td>
</tr>
<tr>
<td>MPD5.4</td>
<td>Optimisation and component grouping of modules/sub-system</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Generic I.D. Process</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ID1</td>
<td>Investigation of customer needs</td>
</tr>
<tr>
<td>ID2</td>
<td>Conceptualisation</td>
</tr>
<tr>
<td>ID3</td>
<td>Preliminary refinement</td>
</tr>
<tr>
<td>ID4</td>
<td>Final concept selection</td>
</tr>
<tr>
<td>ID5</td>
<td>ID product drawing</td>
</tr>
<tr>
<td>ID6</td>
<td>Coordination with engineer, manufacturer and vendor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industrial Design Critical Dimension</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CD1</td>
<td>Utilities</td>
</tr>
<tr>
<td>CD1</td>
<td>Code</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>CD1.1</td>
<td>Ease of use</td>
</tr>
<tr>
<td>CD1.2</td>
<td>Ease of maintenance</td>
</tr>
<tr>
<td>CD1.3</td>
<td>Quality and quantity of interaction</td>
</tr>
<tr>
<td>CD1.4</td>
<td>Safety</td>
</tr>
<tr>
<td>CD1.5</td>
<td>Novelty of user interaction</td>
</tr>
<tr>
<td>CD2</td>
<td>Aesthetics</td>
</tr>
<tr>
<td>CD2.1</td>
<td>Product differentiation</td>
</tr>
<tr>
<td>CD2.2</td>
<td>Pride of ownership, image, fashion</td>
</tr>
<tr>
<td>CD2.3</td>
<td>Communication</td>
</tr>
<tr>
<td>CD3</td>
<td>Cost</td>
</tr>
<tr>
<td>CD3.1</td>
<td>Cost benefits and trade-offs</td>
</tr>
<tr>
<td>CD3.2</td>
<td>Appropriate use of resources</td>
</tr>
<tr>
<td>CD4</td>
<td>Production</td>
</tr>
<tr>
<td>CD4.1</td>
<td>Appropriate usage of raw materials</td>
</tr>
<tr>
<td>CD4.2</td>
<td>Tooling</td>
</tr>
<tr>
<td>CD4.3</td>
<td>Manufacture and assembly</td>
</tr>
<tr>
<td>CD4.4</td>
<td>Packaging</td>
</tr>
<tr>
<td>CD5</td>
<td>Product life-cycle</td>
</tr>
<tr>
<td>CD5.1</td>
<td>Life-cycle design</td>
</tr>
<tr>
<td>CD5.2</td>
<td>Material selection</td>
</tr>
</tbody>
</table>

Table 1. Codes references used in InDFM

Figure 8. Application of InDFM on a conceptual product design process
4.4. Representation of InDFM

The application example of the InDFM is as shown in Figure 8. There are two (2) main parts in the process configuration, which include the conceptual product design process and the InDFM. The conceptual product design process is a process that is either newly proposed or existing. The InDFM elements that specifically relate to the critical dimensions vary between different products. An example of the conceptual product design process of a company collaborating in the research is adopted. The InDFM is applied to the conceptual process through synchronisation of phases in order to appropriately manage the implementation of industrial design in each phase of the conceptual product design process.

To support the users of the InDFM a set of implementation guidelines is provided. These guidelines are intended to provide an appropriate practical approach for utilising industrial design within a generic modular product design process based on the core activities within each phase. Each guideline is presented as a checkpoint table for reference. The checkpoints used in these guidelines enable the user to determine and respond to the requirements needed in order to accomplish the industrial design input tasks. These checkpoints also facilitate the user in establishing the fundamental objectives of utilising industrial design in their development process by providing a breakdown of subjects that need prior consideration.

The implementation of the InDFM will also support the planning and operational aspects of the whole design and development process by the cross functional team. This provides the team with a defined structure of how and when industrial design should be implemented in each phase. This also provides the team with a parameter on the “hard points” (Sanchez, 2002), where changes during component development are not allowed once interfaces between sub-systems of a new product architecture are defined. The InDFM provides a structure that determines the utilisation of industrial design to specific points where the component interface specifications for a new architecture are being investigated, and industrial designers are prepared to work within those interface parameters throughout the design and development process.

5. Conclusion

The development of the InDFM is part of PhD research that aims to provide a systemic approach in optimising industrial design in modular product design and development. The approach is based on the view that industrial design is not fully represented in the modular product development process as an integral part of the design and development strategy where the industrial design process itself represents a large amount of design knowledge. At present the framework is nearing completion and the intention is to perform a qualitative evaluation with a number of European based companies. A model of the InDFM will be presented to the participating companies and retrospectively applied to their existing product development process. Further research on the InDFM will involve implementation of the framework on an actual project, and evaluation and analysis will be done throughout its progress. Further research will also involve the development of the InDFM to support modular product design and development for technology driven products.
By employing the InDFM, it is anticipated that many modular product companies would find it easier to implement and optimise industrial design in their development process in order to produce an exciting, highly competitive and successful product in the market.

References


Index 6

Article II

INTERNATIONAL CONFERENCE ON DESIGN AND INNOVATION
Kuching, Sarawak – Malaysia, 7- 8 November 2011
Innovation of Product Modularity Design through Formal Industrial Design Framework

Muhammad Firdaus Abong Abdullah
Faculty of Applied and Creative Arts, Universiti Malaysia Sarawak
Tel. No.: 082 581406
E-Mail: amfirdaus@faca.unimas.my

Abstract

This article proposes a research of systemic approach to optimize industrial design application in modular product design through a dedicated framework called InDFM, acronym of Industrial Design Framework for Modular Product Design/Development. Industrial design has significant potentials to support design and development of modular product. However, reviews of existing researches and surveys on industrial design application in modular product design showed that there is a lack of comprehensive contributions of industrial design within the existing standard modular product design process. The development of InDFM is derived from the findings acquired from European and Asian based modular product companies. The model of InDFM incorporates core industrial design measures (emphasis, capabilities, outcomes, and management) within modular product design process. The incorporation considers the four modular design principles (separation, unification, connection, and adaptation) as proposed by Doi, to guide industrial design inputs in modular product design. A model of the InDFM is presented to participating companies for process evaluation. This model is applied to new design process and also retrospectively to the existing design process for feasibility validation. The results of the evaluation and validation are used to conduct adjustment to the framework for adaptation to different category of modular products.

Keywords: industrial design, modular product design, framework
Innovation of Product Modularity Design through Formal Industrial Design Framework

INTRODUCTION

This paper is part of a research conducted on industrial design process and its potential to support modular product development. The initial investigation into these fields reveals a hypothesis that product design and development organisations have failed to take full advantages of the industrial design prospects, taking an ad hoc or localised approach to industrial design within their modular product design and development process. Modular product design and industrial design are two design approaches that are familiar with most product organization today, however, there are relatively little documentation or record on the integration of these approaches. This leads the researcher to believe that they have not been studied in any great detail. It should be stressed that the rise of interest for industrial design is an interesting symptom of changes not only in modular product development but in the overall product development environment; therefore more researches into this area are needed.

The aim of this research is to develop a systematic approach to optimise industrial design prospects in modular product design through the introduction of a newly developed framework known as InDFM (Industrial Design Framework for Modular Product Design/Development). The background to the research is the opportunity presented in guiding modular product organisations into taking a more structured and methodical approach to industrial design within their modular product design and development project. This approach is not only relevant to the design aspects of industrial design but also to the overall operationalisation of industrial design.

THE DRIVER FOR A NEW APPROACH

A shift in competitive environment has forced many companies to diversify from the standard mass-market products into variations of similar products or mass-customisation (Kratochvil and Carson, 2005). Thus, the concept of modularity (Sanchez, 2002; Baldwin and Clark, 2000; Kamrani and Salhieh, 2000; Ericsson and Erixon, 1999) was introduced. Growing numbers of global product companies are now not only adopting modularity, but are also adopting new kinds of product strategies and implementing integrated new development processes that are explicitly focused on achieving a range of competitive advantages through modular product design.
General reviews of literatures indicate that the current approaches to modularity are largely the domain of engineers and technical designers and there is little to suggest that the potential role of industrial design within modularity is recognised. Therefore, it is assumed that researchers and product organisations have failed to perceive the strategic importance of the industrial design within the modular product design process. In reality, industrial design has provided critical visual and tactile elements which influence both on immediate sales and on total customer experience over a product’s lifetime. Now industrial design has become vital in product development process and is rapidly being recognized as one of the important strategic tools in product development. However, implementing industrial design involved complicated tasks that require a precisely defined approach. The correlation of industrial design and modular product design is rarely researched and publicized. This situation has prompted a new research into this domain to seek out new understanding on improving industrial design approach within this domain. These concerns ultimately are the goals that prompted the importance of this research. The researcher also believes that it is imperative to fully exploit industrial design throughout any product design processes.

![Philips electric shaver series. Industrial design played a critical role in providing spatial styling variations to the product while maintaining the same degree of user interaction and ergonomics. (Philips Electronics, 2010)](image)

**Figure 1** - Philips electric shaver series. Industrial design played a critical role in providing spatial styling variations to the product while maintaining the same degree of user interaction and ergonomics. (Philips Electronics, 2010)

An example of a successful application of industrial design in modular product design is highlighted by Philips Electronics with its series of electric shavers (Refer to Figure 1). The company has demonstrated in this product family that industrial design played a critical role in providing spatial styling variations while maintaining the same degree of user interaction and ergonomics. Industrial design in products such as illustrated provides significant critical differentiators in developing compelling, and globally competitive brand propositions (Juratovac, 2005; Mostowics and Grzecznowska, 2004). This is supported by Sanchez (2002) that states industrial design as one of the most important strategic tools in developing modular products through:
- Developing design concepts for more extensive product lines in order to increase product variety.
- Refreshing product designs through styling changes in visible components for technologically mature modular products.
- Creating styling variations that can effectively distinguish individual product models within a modular product family.
- Bringing a series of technologically upgraded products to market in rapid succession.
- Providing effective differentiation of new product models by stylisation in order to communicate visually the improved technical performance of the new product.

Based on this strategic importance, it is indicated that there are significant needs to develop an approach to optimise industrial design in modular product design as a growing number of global companies now adopt modularity concepts in managing the technical development of their new products. The issue of industrial design's under-utilised potential has prompted research into a dedicated framework and structured methodology to utilise the full potential of industrial design in a modular product design process. Industrial design implementation must be carefully organized and managed in order to avoid interference to the technical and engineering aspects of the process. The process of industrial design has been described as phases of activities that are primarily user-driven rather than technology driven (Gemser et al., 2006). This implies that the industrial design process relates mainly to aspects between user and the product. Therefore activities that relate to the technical and engineering aspects do not fall under industrial design.

**INDFM CONSTRUCT**

The InDFM environment (Refer to Figure 2) is oriented towards supporting and optimising industrial design potential benefits in any modular product design and development processes, and is flexible to adapt to any changes within the used and future modular design stages. This will in turn provide greater speed and flexibility in developing new modular products in addition to supporting faster and cost-effective upgrading of technology for existing products. The final outcome of the application is the production of greater and improved modular product variants.

The objectives of the proposed framework are specified as followed:
- *Industrial design optimisation tool* – provides a method to optimise the potential of industrial design benefits with emphasis on industrial design innovativeness approach.
- **Industrial design management tool** – supports the integration of industrial design process into the existing modular product design process through defined management structures and practices set up to deploy industrial design and to maximize industrial design outcomes.

- **Collection and transmission of industrial design data** – support systematic input of industrial design data into the modular product design process, and systematic distribution of the data throughout the process for innovative and creative product properties outcome.

- **Enhancement of product design process** – supports the enhancement of any modular product design process through the addition of a clearly defined structure containing new design and development elements which are adaptable to changes within any used modular design process stage.

![Figure 2 – Overview of InDFM environment](image)

<table>
<thead>
<tr>
<th>Key Constituents</th>
<th>Stage and description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ISO 9001 Design and development process</td>
<td>Customer requirement; design input; design; design output; design validation; product release.</td>
</tr>
<tr>
<td>2. Industrial design process</td>
<td>Customer needs investigation; conceptualization and design; preliminary refinement; final concept selection; i.d. product drawing; co-ordination.</td>
</tr>
<tr>
<td>3. Modular product design process</td>
<td>Customer needs analysis; product requirement analysis; product concept analysis; product concept integration.</td>
</tr>
<tr>
<td>4. Principles of modular design</td>
<td>Separation of modules; unification (standardization) of modules; connection of modules; adaptation of modules.</td>
</tr>
</tbody>
</table>

**Table 1** – Key constituents of InDFM
The key constituents in the building of the InDFM are shown in Table 1. The overviews of each of the key elements are described in the following paragraphs. These key constituents formed the backbone of the framework.

The ISO 9001 Design and development process (Refer to Figure 3) should be considered ideal since it is based directly on ISO 9001 (Schoonmaker, S.J., 1997; ASQC, 1995). This most basic view can and should be compared to the ISO 9001 standard paragraph 4.4 on Design Control which is the most crucial area of the standard for the design section of an organisation.

The configuration of the process stages as shown however is an approximation of the ideal process as any real design and development process is much more complex than the one shown. In this case, the integration of other process such as industrial design may be done throughout the entire process or in specific stages within the process. Adding industrial design into the ideal ISO 9001 process activities will add complexity to the process thus requiring integration tool that is prudently structured. While industrial design encourages creativity throughout its processes, these approaches should be mediate to ISO 9001 in order to ensure that the product released meets the international design standard. By working industrial design within ISO 9001 would eliminate or minimises the amount of product deficiency by meeting the customer’s requirement on initial interaction with the product.

Figure 4 – Generic industrial design process (Adopted from: Ulrich & Eppinger, 2000)
Modern industrial design is derived from complex amount of processes which involved extensive research and definition into the product architecture, user needs, styling, and corporate strategies (Candi, M. & Gemser, G., 2010; Sanchez and Collins, 2001). Industrial design however cannot be perform solitarily as it must be integrated into the total design and development process in order to achieve the intended industrial design outcome of a product. The generic process of industrial design (Refer to Figure 4) may not necessary correspond to each of the modular product design process stage therefore the user of InDFM need to determine the appropriate stages for its application. For each stage of the process, the emphasis is given to achieve the final goals of satisfying both the manufacturer and consumer needs by continuously considering the industrial design critical outcomes (Refer to Table 2).

<table>
<thead>
<tr>
<th>Industrial Design Critical Outcome</th>
<th>Outcome Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Usability (Utilities)</td>
<td>Ease of use; ease of maintenance; quality and quantity of interaction; safety; novelty of interaction; ergonomics</td>
</tr>
<tr>
<td>2. Aesthetics</td>
<td>Product differentiation; pride of ownership, image and fashion; communication.</td>
</tr>
<tr>
<td>3. Costs</td>
<td>Cost benefits and trade-offs; appropriate usage of resources.</td>
</tr>
<tr>
<td>4. Production</td>
<td>Manufacture and assembly; appropriate usage of raw materials; tooling; packaging.</td>
</tr>
<tr>
<td>5. Product life-cycle</td>
<td>Life-cycle design; material selection</td>
</tr>
</tbody>
</table>

Table 2 – ID critical outcome and objective

Modularity is a powerful design strategy which is now becoming an integral part of mainstream strategic management thinking (Sanchez, 2002). Modularity is a particular design structure, in which parameters and tasks are interdependent within units (module) and independent across them (Clark and Baldwin, 2000). From this definition, one can therefore define that modular product design process is the method of creating and developing a product that possess a modular structure.

Figure 5 – Modular product design process ( Adopted from: Kamrani & Salhieh, 2000)
Modular product design involves four stages (Refer to Figure 5). The process begins with customer needs analysis, followed by product requirement analysis. The results from the first two stages are used to identify the product requirements through a list of functional objectives needed to meet the customer’s primary needs. The third stage of the process is product or concept analysis which is the decomposition of the product into its basic functional and physical elements. These elements must be capable of achieving the product’s functions. The final stage of the process is product or concept integration, where the basic physical and functional components resulting from the decomposition process are arranged in modules and integrated into a functional system.

<table>
<thead>
<tr>
<th>Principles</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Separation</td>
<td>Emphasis is put on finding the method of disintegrating modules into a proper number of modules and determining a group of standardized modules according to the design purpose.</td>
</tr>
<tr>
<td>2. Unification</td>
<td>Module should be standardized in full consideration of not only its dimensional specifications, but also its functionality, capability, and structural configuration.</td>
</tr>
<tr>
<td>3. Connection</td>
<td>In employing modular design, the jointing (or connection) method and joint surface should be unified or standardized in the most preferable case while maintaining allowable assembly accuracy.</td>
</tr>
<tr>
<td>4. Adaptation</td>
<td>Various structural configurations with the varied functionalities, performances, and dimensional specifications should be arbitrarily produced from a group of modules. The preferable combination and interfacing method among modules are established and evaluated to ensure modules compatibility.</td>
</tr>
</tbody>
</table>

Table 3 – Principles of modular design (Adopted from: Doi; Ito, 2008)

In conducting the modular product design process, a design engineer should adhere to the four principles (Refer to Table 3) of modular design. Although the principles were laid out in the context of machine tools design (Ito, 2008), these principles are still very much relevant and valuable in rationally guiding the design of any other modular product today. The application of industrial design potentials into a modular product should adheres to these principles whereby industrial designer should work around these principles to ensure that industrial design potentials do not disrupt the product modular characteristics, which could affect the modularity performances of the product.

INDUSTRIAL DESIGN MEASURES

The terminology of industrial design defers in perspective and application, therefore the terms of the kind of measures used for industrial design also varies. Generally, there are four categories of industrial design measures or operationalizations (Candi, M., and Gemser, G., 2010). These include industrial design emphasis, capabilities, outcomes, and managements. These measures form one of
the vital aspects of the InDFM mechanism. Having both the processes integrated within the ideal ISO 9001 process standard, and the industrial design creative inputs adhered to the principles of modular design; these measures are an important consideration to mark out the application potentials within the design and development process. The following paragraphs further elaborate the categories.

Industrial design emphasis is connected with an organization’s strategy on industrial design in their product design activities including the degree to which industrial design involvements. To examine the relationship between industrial design and performance, a common approach is to focus on the industrial design capabilities available and exploited when designing and developing a new product. The number of in-house industrial designer or external design consultants (Gemser and Leenders, 2001) used in modular product design project is one of the important aspect related to capabilities measure. Industrial design outcomes are defined as the exhibited industrial design characteristics of a product. They are the measure of “goodness” of a product which is generally associated to areas of usability and utilities, aesthetics, cost, manufacturability, and product life-cycle. The industrial design outcomes formed the most vital component of the InDFM as its attributes in particularly aesthetics and usability aspects have profound impact on user perception of successful industrial design. Industrial design management capabilities are structures and practices set up to deploy industrial design and to maximize industrial design outcomes. Effective industrial design management is needed to achieve effective industrial design investment (Chiva and Alegre, 2009).

MECHANISM OF INDFM

![Diagram]

Figure 6 – The complete InDFM configuration
The InDFM is made of a clearly defined structure consist of the integration of the vital elements organized within the ideal ISO 9001 Design and development process. The integration of all the elements in InDFM is completed through applications or adaptation of the industrial design measures to meet the framework specified objectives. The general configuration (Refer to Figure 6) acts as reference to those involve and responsible for project management, design and engineering. Any real activities and integrated process are much more complex than the one shown. The activities of implementing industrial design measurements are conducted within the product development organisation (represented by a dashed line). Beyond this boundary is the external customer of the released product. The process starts with the definition of industrial design measurements which are generally done by the top management with inputs from industrial design team. This group will have the control over the decision on whether industrial design is needed within the specific stage of the product design stage. Industrial design measurements are directly adopted or implement within the modular product design process.

The implementation process require the industrial design measurements to be aligned with the modular product design stages (Refer to Figure 7) in order to determine the appropriate stage where industrial design should be. Emphasis must be given to industrial design outcomes as they contains the creative industrial design aspects that concerned directly to the design outlook and functionality of the tangible product. The execution of this measurement must adhere to the modular design principles so not to jeopardise the modular characteristics and performances of corresponding modules.

Figure 7 – The potential timeline for industrial design operationalisation within the modular product design process. The creative industrial design inputs are mainly implemented within the product analysis and integration phase of MPD.
The implementation of the InDFM requires close cooperation between members of industrial design and engineering design teams. Once the emphasis of industrial design has been confirmed, the groups must then decide on the actual capabilities of industrial design such as the numbers of industrial designers and the facilities required to perform the industrial design tasks within the process. The industrial design tasks are associated to the outcomes, which are the creative aspects. These are the critical areas where aesthetics and functionality values are applied to the product.

To enable the design team to map and identify the industrial design aspects into each phase of modular design process, mapping codes (Refer to Table 4) have been established. The codes represent the three vital elements – modular product design process, generic industrial design process, and industrial design outcomes. The groups of codes are also an important tool used to analyse the appropriateness of industrial design aspects within the specific phase (Refer to Figure 8).

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Modular Design Process (MPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPD1</td>
<td>Project Definition</td>
<td></td>
</tr>
<tr>
<td>MPD2</td>
<td>Customer Needs Analysis</td>
<td></td>
</tr>
<tr>
<td>MPD2.1</td>
<td>Identifying needs</td>
<td></td>
</tr>
<tr>
<td>MPD2.2</td>
<td>Analysis approaches</td>
<td></td>
</tr>
<tr>
<td>MPD2.3</td>
<td>Needs grouping and prioritisation</td>
<td></td>
</tr>
<tr>
<td>MPD2.4</td>
<td>Satisfying customer needs</td>
<td></td>
</tr>
<tr>
<td>MPD3</td>
<td>Product Requirement Analysis</td>
<td></td>
</tr>
<tr>
<td>MPD3.1</td>
<td>Identifying requirement (functional analysis)</td>
<td></td>
</tr>
<tr>
<td>MPD3.2</td>
<td>Weighing general function requirement</td>
<td></td>
</tr>
<tr>
<td>MPD4</td>
<td>Product/Concept analysis</td>
<td></td>
</tr>
<tr>
<td>MPD4.1</td>
<td>Product/Concept generation</td>
<td></td>
</tr>
<tr>
<td>MPD4.2</td>
<td>Decomposition – functional elements (technical – engineering)</td>
<td></td>
</tr>
<tr>
<td>MPD4.3</td>
<td>Decomposition – physical elements (physical form design)</td>
<td></td>
</tr>
<tr>
<td>MPD5</td>
<td>Product/Concept integration</td>
<td></td>
</tr>
<tr>
<td>MPD5.1</td>
<td>System level specification (SLS)</td>
<td></td>
</tr>
<tr>
<td>MPD5.2</td>
<td>Identification of SLS impact on QIR</td>
<td></td>
</tr>
<tr>
<td>MPD5.3</td>
<td>Components similarity (code and matrix)</td>
<td></td>
</tr>
<tr>
<td>MPD5.4</td>
<td>Modular (and sub-systems) component grouping &amp; optimisation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>General ID, Process (ID)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID1</td>
<td>Investigation of customer needs</td>
</tr>
<tr>
<td>ID2</td>
<td>Conceptualisation</td>
</tr>
<tr>
<td>ID3</td>
<td>Preliminary refinement</td>
</tr>
<tr>
<td>ID4</td>
<td>Final concept selection</td>
</tr>
<tr>
<td>ID5</td>
<td>User product viewing</td>
</tr>
<tr>
<td>ID6</td>
<td>Coordination with engineer, manufacturer and vendor</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Industrial Design Critical Dimension/Outcome (CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD1</td>
<td>Utilities</td>
</tr>
<tr>
<td>CD1.1</td>
<td>Ease of use</td>
</tr>
<tr>
<td>CD1.2</td>
<td>Ease of maintenance</td>
</tr>
<tr>
<td>CD1.3</td>
<td>Quality and quantity of interaction</td>
</tr>
<tr>
<td>CD1.4</td>
<td>Safety</td>
</tr>
<tr>
<td>CD1.5</td>
<td>Sensory of user interaction</td>
</tr>
<tr>
<td>CD2</td>
<td>Aesthetics</td>
</tr>
<tr>
<td>CD2.1</td>
<td>Product differentiation</td>
</tr>
<tr>
<td>CD2.2</td>
<td>Pride of ownership, image, fashion</td>
</tr>
<tr>
<td>CD2.3</td>
<td>Communication</td>
</tr>
<tr>
<td>CD3</td>
<td>Cost</td>
</tr>
<tr>
<td>CD3.1</td>
<td>Cost benefits and trade-offs</td>
</tr>
<tr>
<td>CD3.2</td>
<td>Appropriate use of resources</td>
</tr>
<tr>
<td>CD4</td>
<td>Production</td>
</tr>
<tr>
<td>CD4.1</td>
<td>Appropriate usage of raw materials</td>
</tr>
<tr>
<td>CD4.2</td>
<td>Testing</td>
</tr>
<tr>
<td>CD4.3</td>
<td>Manufacturing and assembly</td>
</tr>
<tr>
<td>CD4.4</td>
<td>Packaging</td>
</tr>
<tr>
<td>CD5</td>
<td>Product life-cycle</td>
</tr>
<tr>
<td>CD5.1</td>
<td>Lifecycle design</td>
</tr>
<tr>
<td>CD5.2</td>
<td>Material selection</td>
</tr>
</tbody>
</table>

Table 4 – InDFM pre-defined codes description. The ID and CD codes are mapped on the MPD codes to analyse and identify the appropriate industrial design aspects for each modular design phase.

Figure 8 shows the how the coding are used to determine the industrial design outcome in the ‘system decomposing’ stage of modular product design process. This stage consists of three design activities – concept generation, basic functional element, and basic physical components.
industrial design outcomes (CD) in these activities are decided by the design team with reference to industrial design emphasis. An example of product decision process is shown in Figure 9.

Figure 8 – An example of industrial design outcomes implementation (represented in codes) in System Decomposing (Stage 4) of modular design process.

Figure 9 – A simplified selection diagram of a decision process model for a projectile launcher.
FRAMEWORK EVALUATION

The InDFM was introduced to a European company participating in this research. This company is involved in design, development and manufacturing of defence equipments. Due to the nature of the company’s business and the mutual agreement between the company and researcher, the name of the company is not disclosed. Industrial design is not practiced formally by the company as there is no certified industrial designer in their employment. Therefore, the company is finding implementing industrial design to their product difficult.

To evaluate its feasibility, the InDFM model is applied to a newly developed modular product design process provided by the company. The Figure 8 shows the integration of InDFM and the new process.

![Figure 8](https://example.com/figure8.png)

Figure 8 – Case study 1: Implementation of InDFM on conceptual (new) modular product design process of a defence company showing industrial design outcomes is concentrated in system decomposing and modular system optimisation phase. These phases are consistence with the development stage of the conceptual process.

The InDFM is also retrospectively applied to their existing design process. The benefits gained from the implementation of InDFM have been prevalent. New modular product design incorporating industrial design characteristics is much simplified and responsive. Design changes and upgrades on the existing process have also benefited in similar way through forward compatibility and
the ability to enhance selective modules, addressing outcomes requirements pre-emptively and allowing existing process to be upgraded with greater efficiency.

CONCLUSION

The development of the InDFM is part of a research that aims to provide a systemic approach in optimising industrial design in modular product design and development to be used by product companies that intend to apply or are new to industrial design. The approach is based on the view that industrial design is not fully represented in the modular product development process as an integral part of the modular product design and development strategy, where the industrial design process itself represents a large amount of design knowledge that produced creative and innovative outputs. At present the framework is still being evaluated with a number European and Malaysian based companies. The first case study have shown that industrial design confers a range of product and process based enhancements that together formed a package for meeting current and future requirement of innovative and creative solution through industrial design.

Primarily the research on industrial design in modular product design has addressed the need for a structured approach and the specific methodology to meet the needs. Further research is targeted at providing support tools for the process through analysis of a computer based methodology environment for both user and technology driven modular products.

REFERENCES


