# Development of a Tool for Building Shared Representations among Industrial Designers and Engineering Designers

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## Abstract

Previous studies have demonstrated the importance of multi-disciplinary collaboration in New Product Development (NPD). As such, interactions between industrial designers and engineering designers have become increasingly important. This research project aims to build a shared understanding between the 2 disciplines during NPD. Following empirical research that revealed collaboration-related problem areas, as well as collecting data concerning the use of design representations, a card system was developed to provide information on the role and significance of design representations, leading to joint understanding, improved communication and creation of shared knowledge. When asked in the validation study if the system would foster collaboration, 68.2% of industrial designers and 63.2% of the engineering designers gave a good and excellent rating, indicating that the system could play a significant role towards the support of multi-disciplinary teamwork.

## Keywords

collaboration, design representation, industrial design, engineering design, new product development, product design

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(Word count: 6545 words)

# 1. Introduction

## *1.1 Inter-disciplinary Collaboration during NPD*

The complex and competitive nature of New Product Development (NPD) requires effective integration where members are drawn from different functions to integrate their expertise in conceptualising, developing and commercialising innovative products (Nemhard and Edmondson, 2009). Despite the importance of inter-disciplinary collaboration, few studies have examined the relationship between industrial design and engineering design.

For this study, industrial design encompasses the specification of product form including aesthetic judgement, semantics, user interface and social requirements (IDSA, 2006; Tovey, 1994; Flurscheim, 1983). In contrast, the term engineering design broadly encompasses mechanical, electrical and electronic engineering (Fielden, 1963), all of which employ science-based problem solving methods (Hurst, 1999). The aim of this research was to investigate problems associated with collaborative interaction between industrial designers and engineering designers. More specifically, it was proposed that having a standardised understanding in the use of design representations could potentially bridge the gap between both disciplines during the NDP process.

Disharmony during NPD may occur when team members approach a project differently. For instance, industrial designers adopt open-ended solutions, using instinct and trial-and-error to embody personal creativity for the design, whilst engineering designers viewed problems as precise and focus on functionality, specifications and performance (Kim and Philpott, 2006). In terms of deliverables, engineering designers produce technical details for manufacture, based on quality, performance and cost (Flurscheim, 1983); while industrial designers deliver visual representations such as sketches and physical models. As a result, their dissimilar views and contrasting outcomes may create conflict (Persson, 2002).

Previous research has mainly focused on inter-disciplinary collaboration between engineering design and manufacturing (Beskow, 1997; Ulrich and Eppinger, 2000) and engineering with marketing (Griffin and Hauser, 1996; Shaw and Shaw, 1998). With the exception of Persson and Warell (2003) who identified methods and tools adopted by industrial designers and engineering designers, little research has been done to investigate the collaborative interaction between industrial designers and engineering designers. Persson and Warell (ibid) also reported that communication, social factors, personality differences and physical settings were key factors in influencing professional interaction. Persson (2005) went on to propose a collaborative workspace with a joint mindset by means of socialisation and mediating instruments to enhance collaboration. Other integrating mechanisms included social organisation (Kahn, 1996; Jassawalla and Sashittal, 1998), the use of inter-communal negotiation for better cross-functional teamwork (Brown and Duguid, 2001), having boundary-spanning and good teaming skills (Nemhard and Edmondson, 2009) and employing information and communication technology (Sproull and Kiesler, 1991; Toye, et al. 1993). Although other established methods such as Quality Function Deployment (QFD) and stage-gate solutions are available (Ulrich and Eppinger, 2000), they are primarily designed for engineers. As such, very few integrating mechanisms are available to enable, facilitate or improve collaboration been industrial designers and engineering designers.

Rothwell (1992) proposed that effective communication and cross-functional linkages are the primary factors for successful NPD. Communication can be made effective by transmitting symbols precisely; ensuring that the meaning is relayed correctly; receiving the intended meaning accurately; and reaching the right audience through proper distribution (Chiu, 2002). Although communication mechanisms do exist, researchers have observed that industrial designers and engineering designers still do not understand each other well (Fiske, 1998). For instance, identical words may not have the same meaning; or 2 different words can mean the same. Communication only becomes accurate and effective when the team develops a common vocabulary and by understanding the communicative codes and language within the message content (Persson and Warell, 2003). In addition, collaboration represents a higher level relationship when compared to communication that is limited to information exchange. Jassawalla and Sashittal (1998) stated that collaboration occurs when participants command equal interest, adopt transparency with high awareness, are mindful through integrated understanding, and perform with synergy. Collaboration allows members from different teams to divide work effectively, assist each other in maximising their joint contribution, and communicating accurate information such as through the use of precise design representations.

### *1.2 Standardising the Use of Design Representations*

Design representations can be expressed through language, graphic or artefacts (Goel 1995; Goldschmidt, 1997) and they refer to models of the object being symbolised (Palmer, 1987). During the early stages of NPD, representations such as sketches are quick and unstructured. As the design develops, more structured methods such as drawings and models appear. Leonard-Barton (1991) noted that the progression of having more information embedded within a representation enhances the understanding of the design. On a personal level, sketches contribute to visualisation, communication and information storage (Tang, 1991); for externalising ideas (Larkin and Simon, 1987); to assist in thinking (Ferguson, 1992; Suwa, Purcell and Gero, 1998); to verify decisions (Herbert, 1993); and to allow a range of interpretations for a design solution (Scrivener, 2000). Therefore, accurate and effective representations not only aid the design process at an individual level but also enhance collaboration within multi-disciplinary teams.

While many forms of design representations are available, sketching is seen as being central during the early stages of NPD. Goel (1995) sees sketches as the first step of the design process to externalise and visualise ideas at an individual level. At the next stage, representations are used to communicate with others and include presentation drawings and physical models. In the later stages, detailed technical drawings and prototypes are used for communicating details (Goldschmidt, 1992). In comparing the differences between representations favoured by the 2 disciplines, Veveris (1994) observed that engineering designers used models associated with engineering principles, functional mechanisms, production issues; whereas industrial designers applied representations related to appearance and usability. Despite the various attempts to classify representations by other authors (Tjalve *et al*. 1979; Ullman, 1988; Tovey, 1989; Evans, 1992; Ferguson, 1992; Goldschmidt, 1992; Veveris, 1994; Kavakli *et al*., 1998;

Cross, 1999; Do *et al*., 2000; Otto and Wood, 2001; Cain, 2005; Olofsson and Sjölén 2005; Pavel 2005; Pipes 2007; Eissen and Steur 2008), they are largely incomplete or do not incorporate both industrial design and engineering design representations. In addition, researchers have noted problems with their use when symbolic elements become unclear. The more incomplete or vague a representation is, the greater and wider the perceptual interpretation space becomes. Despite such drawbacks, ambiguous representations allow for creativity and to generate open-ended solutions (Rodriguez 1992, Ehrlenspiel and Dylla 1993, Fish 1996). They enable seeing things in a different way that in turn produces new designs and allows flexibility in terms of design attributes.

Although ambiguous representations possess benefits, their ill-defined nature makes it difficult for engineering designers to comprehend and recognise how they work in relation to a product's technical parameters (Saddler, 2001). It may be difficult for a viewer other than the originator to understand the embodied meaning, context or scale (McGown, et al., 1998). The need for accurate and effective representations has been shown by Stacey and Eckert (2003) who provided an example of confusing sketches used in the knitwear industry. They cited that although the lines of a garment sketch were intended to describe the structure pattern, they could be misinterpreted as being stripes on the fabric.

In light of these theoretical arguments, the authors sought to conduct a series of investigations to first examine and confirm the potential barriers between the 2 disciplines occurring during NPD before developing a tool that would enhance understanding between the 2 disciplines.

## 2. Empirical Research

For this study, empirical research by means of quantitative and qualitative methods through semi-structured interviews and observations were used. The research was undertaken as a 2-stage process whereby the purpose of first part was to investigate and confirm the potential barriers between the 2 disciplines. The objective of the second part was to understand the application of design representations employed by industrial designers and engineering designers during NPD. The next section discusses the initial investigations that were carried out.

### *2.1 Initial Investigation*

#### 2.1.1 Interview Study

In the first part of the investigation, 10 weeks were spent interviewing experienced industrial designers and engineering designers from 17 industrial design consultancies specialising in consumer electronic products and from tertiary institutions. There was a good balance of large (more than 10 design staff), medium (between 6-10 design staff) and small industrial design consultancies (less than 5 designers) to allow a wider sampling and to obtain findings from a larger pool of respondents. Altogether, 61 interviews were conducted with an equal number of industrial design and engineering design managers, academics and practitioners. By interviewing the practitioners, it enabled first-hand accounts to be obtained; while interviewing project managers allowed the research to obtain a management perspective. Interviewing the educators enabled their views concerning this research to be heard from an academic viewpoint and whether the design representations were correctly identified. For consistency, the respondents had the same interviewer and were subjected to same interview process with the same interview questions. In addition, the companies chosen had to be involved in NPD concerning consumer electronic products, employing both industrial designers and engineering designers during the design process.

A semi-structured interview was used as it would sufficiently explore issues yet providing flexibility within an organised format. It allowed respondents to fully describe their personal experiences relating to group interaction and inter-disciplinary collaboration. The interviews lasted a total of 45 hours which first introduced the aims of the study. The respondents were asked 10 questions in order to gather general demographic data about their educational background, work experience and the company structure (Table 1).

| **Background questions** |
|---|
| 1. Date of interview |
| 2. Name of Interviewee |
| 3. Position of respondent |
| 4. Role & Responsibility |
| 5. Educational background |
| 6. Years of experience |
| 7. Company name and type |
| 8. Number of industrial designers / engineering designers in company |
| 9. Number of industrial designers / engineering designers in the project |
| 10. Describe the company structure and culture |

Table 1: Background questions

Next, they were asked project-specific questions to identify factors that might have influenced collaborative work. It required an example of a project, relating experiences of group interaction, reasons for project successes and failures, as well as tools and methods used for the project (Table 2).

| Research-specific questions |
|---|
| 1. Describe a recent project undertaken |
| 2. Describe the design approach and strategy adopted |
| 3. What was the project deliverable? |
| 4. What activities were involved? |
| 5. Describe the tools and methods used |
| 6. What design representation methods were used? |
| 7. Did collaboration between industrial designers and engineering designers occur during the project? |
| 8. Describe the quality of group interaction and teamwork |
| 9. What factors might have influenced group work? |
| 10. Were there any leadership or management issues? |
| 11. Name the success or failure factors |
| 12. What is your view of the final product? |
| 13. Did you have any personal concerns working with the other discipline? |
| 14. Suggest some improvements for future collaborative work |

Table 2: Research-specific questions

The interviews identified 61 issues relating to inter-disciplinary collaboration which were encoded into a spreadsheet. A coding and clustering technique was then used to analyse the qualitative data and to help build theory (Miles and Huberman, 1994), as well as reducing data into themes and relationships (Strauss and Corbin, 1990). Such pattern coding has been similarly used by other researchers (Purcell *et al*., 1996) in order to summarise findings into condensed categories. The 61 issues were re-organised with the most frequently occurring problems in a descending order as shown on the right column of the chart (Table 3). From the matrix, it became evident that 3 main problem areas were barriers to collaboration among industrial designers and engineering designers which are now discussed:

| | Issues | Company | | | | | | | | | | | | | | | | | Occurances | Category |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | |
| 1 | Having knowledge of the other field | | | | | ■ | ■ | ■ | ■ | ■ | | ■ | | | ■ | | ■ | | 8 | A |
| 2 | Conflict in Principles | ■ | | ■ | | | ■ | ■ | | | ■ | | ■ | | | | | | 6 | A |
| 3 | Choosing the right tools and methods | ■ | ■ | | | ■ | ■ | ■ | | | | | | ■ | | | | | 6 | B |
| 4 | Communication Skills | ■ | | | | | ■ | | | ■ | | | | ■ | ■ | | | ■ | 6 | B |
| 5 | Use of Representation | | | | ■ | ■ | ■ | | | ■ | | ■ | | | ■ | | | | 6 | B |
| 6 | Understanding each other | | | ■ | ■ | | | | | | | ■ | | | ■ | | ■ | | 5 | A |
| 7 | Fixed Engineering Mindset | ■ | | | | | ■ | | | ■ | ■ | ■ | | | | | | | 5 | C |
| 8 | Individual Differences & Attitude | | | ■ | | | ■ | | | | | ■ | | | ■ | ■ | | | 5 | C |
| 9 | Direction of Project Manager | | | | | | | ■ | | | | | ■ | | ■ | ■ | ■ | | 5 | A |
| 10 | Use of Rapid Prototype for Representation | | ■ | | ■ | | ■ | | | | | ■ | | | | | | | 4 | B |
| 11 | Designers and Engineers having Different Values | | ■ | | | | ■ | | | | ■ | | ■ | | | | | | 4 | C |
| 12 | Having a Common Goal | | | ■ | | | ■ | | | | | | | | ■ | | | | 3 | A |
| 13 | Get-together updates / Milestones | | | | | | ■ | | ■ | | | | | | ■ | | | | 3 | B |
| 14 | Informal Meetings | ■ | | | | | ■ | | | | | | | | ■ | | | | 3 | A |
| 15 | Understanding through Experience | | | | ■ | | | ■ | | | | | | | ■ | | | | 3 | C |
| 16 | Translation from 2D to 3D | | | | | | ■ | | | | | ■ | | | | | | ■ | 3 | B |
| 17 | Company Emphasis on Design or Engineering | | | | | ■ | | | | | | | ■ | | | | | ■ | 3 | A |
| 18 | Educational Background of Individual | | ■ | | | | | ■ | | | ■ | | | | | | | | 3 | C |
| 19 | Western vs Asian approach of working | | ■ | | | | | | | | ■ | | | | | ■ | | | 3 | C |
| 20 | Conflict in Interest | ■ | | | | | | ■ | | | | | | | | | | | 2 | - |
| 21 | Fixed Working Protocols | | | | | | ■ | ■ | | | | | | | | | | | 2 | - |
| 22 | Location of support members | | | | | | ■ | | | | | | | | ■ | | | | 2 | - |
| 23 | Trust as a high-level understanding | | | | | | | | | | | | | | ■ | ■ | | | 2 | - |
| 24 | Knowing the technical requirements | | | | | | ■ | | | | | ■ | | | | | | | 2 | - |
| 25 | Working towards Joint-Solutions | | | | | | | | | ■ | | | | | ■ | | | | 2 | - |
| 26 | Production & Manufacturing Limitations | | | | | | | ■ | | | | ■ | | | | | | | 2 | - |
| 27 | Company Culture | ■ | | | | | | | | | | | | | | ■ | | | 2 | - |
| 28 | Engineers do not Understand Role of Designers | ■ | | | | | | | | | | | | ■ | | | | | 2 | - |
| 29 | Teamworking & Team Dynamics | ■ | | | | | | ■ | | | | | | | | | | | 2 | - |
| 30 | Having standard Computer files | | | ■ | | | ■ | | | | | | | | | | | | 2 | - |
| 31 | Limitations in Time leading to Poor Engineering | | | | | | ■ | | | | | | | | | | | ■ | 2 | - |
| 32 | Limitations to size of Electronic Components | | | | | | | | | | | | ■ | | | | ■ | | 2 | - |
| 33 | Creativity and Flexibility of Engineer | | | | | ■ | | | | ■ | | | | | | | | | 2 | - |
| 34 | Marketing controls Budget affecting Design Quality | | ■ | | | | | | | | | | | ■ | | | | | 2 | - |
| 35 | Language as a Probable Barrier | | | | ■ | | | | | ■ | | | | | | | | | 2 | - |
| 36 | Knowing who is in charge / Roles & Responsibilities | | | | | | | | | | ■ | | | ■ | | | | | 2 | - |
| 37 | Team Dynamics | | | | | | | ■ | | | | | | | | | | | 1 | - |
| 38 | Being specific | | | | ■ | | | | | | | | | | | | | | 1 | - |
| 39 | Designers getting carried away & fall behind time | | | | | | | | | | ■ | | | | | | | | 1 | - |
| 40 | Using standard codes | | | | ■ | | | | | | | | | | | | | | 1 | - |
| 41 | Having Multi-cultural Teams | | | | | | | | | | | | | | ■ | | | | 1 | - |
| 42 | Having Multi-disciplinary Teams | | | | | | | | | | | | | | ■ | | | | 1 | - |
| 43 | Fostering Team-spirit | | | | | | | | | | | | | | ■ | | | | 1 | - |
| 44 | Complexity of Project | | | | | | | | | | | ■ | | | | | | | 1 | - |
| 45 | Marketing Understand Designers Working | | | | ■ | | | | | | | | | | | | | | 1 | - |
| 46 | Designers Understand Manufacturing Constrains | | | | | | | | | ■ | | | | | | | | | 1 | - |
| 47 | Testing, Reviewing, Changing, Refining | | | | | | | | | | | | | | ■ | | | | 1 | - |
| 48 | Marketing should be faster to React | | | | | | | | | | | | | | ■ | | | | 1 | - |
| 49 | Engineering Issues affecting Design Aesthetics | | | | | | | | | | | | | | ■ | | | | 1 | - |
| 50 | Client Changes affecting Design Process | | | | ■ | | | | | | | | | | | | | | 1 | - |
| 51 | Designers not understanding Marketing Viewpoint | ■ | | | | | | | | | | | | | | | | | 1 | - |
| 52 | Trimming Cost affecting Design Aesthetics | | | | | | ■ | | | | | | | | | | | | 1 | - |
| 53 | Difficulty in Explaining visual effects to Engineers | | | | | | | | | | | ■ | | | | | | | 1 | - |
| 54 | How Company & Organization Values each field | | | | | | | | | | | | | | | | | ■ | 1 | - |
| 55 | Software Incompetence | | | | | | | | | | | | | | | | | ■ | 1 | - |
| 56 | Proper justification for each decision to Understand | | | | | | | | | | | | | | | | ■ | | 1 | - |
| 57 | Using Technology for Enhanced Communication | | | | | | | | | | | | ■ | | | | | | 1 | - |
| 58 | Changes in Design due to Safety Requirements | | | | | ■ | | | | | | | | | | | | | 1 | - |
| 59 | Client Involvement in Design Stage | | | | | | | ■ | | | | | | | | | | | 1 | - |
| 60 | Education as a means to close gap btw Eng & Des | | | | | | | | | | ■ | | | | | | | | 1 | - |
| 61 | Difference between a Designer and Artist | | | ■ | | | | | | | | | | | | | | | 1 | - |

Table 3: Matrix of 61 problem categories tabulated from interviews

The 3 key problem areas identified from the interviews were:

1. Problem Category A - Conflicts in values and principles:

The first category is concerned with differences in values and working principles. It was found that engineering designers worked systematically based on quantified solutions. In contrast, industrial designers favoured an open-ended approach and used open solutions.

2. Problem Category B - Differences in design representation

The investigations noted the use of different representation methods. Engineering designers often used technical terms and facts that included calculations, technical information and specifications; whereas industrial designers used freehand sketches and drawings to communicate ideas.

3. Problem Category C - Education differences

It was found that engineering designers were taught to employ systematic problem solving and to justify solutions with facts; whereas industrial designers were taught to solve problems intuitively, rarely relying on quantified data. Due to differences in their educational background, both professions had different specialisations, approaches and expectations.

### 2.1.2 Observation Study

Following the interviews, observations were conducted to obtain detailed information by being close to the field of study. The use of observations is advantageous as it allows the researcher to examine interaction taking place between engineering designers and industrial designers in their natural working environment and to record potential barriers that might have occurred. The observations took place throughout a commercial project over 2 consecutive weeks and involved the design of a consumer product with an industrial designer and an engineering designer working together. They were conducted at a design consultancy within its normal work environment and took place from the beginning of the project (design briefing) to the embodiment stage (3D CAD modelling). As video and voice recordings were not allowed due to project confidentiality, note taking was used as it allowed conversations to be recorded and enabled first-hand accounts of the interaction to be documented. Reliability was achieved by cross-checking records (done during breaks to minimise work disruption). Other documents, including reports, specification lists and physical or virtual artefacts provided a better understanding of the activities. To obtain a holistic view of issues within the project, the observations included the project leader, industrial designer and engineering designer.

From the observations, it was found that formal and informal meetings were extremely valuable in enhancing collaboration. Co-location was an important factor since both industrial designers and engineering designers were closely located and had greater interaction as compared to other departments who were on a different floor in the building. The observations recorded different working approaches. Engineering designers focused on technical properties and cost whereas industrial designers emphasised on form and expression. In addition, the lack of a common language in design representations caused miscommunication where certain words were interpreted wrongly. For example, the engineers had intended simple sketches yet the designers interpreted their task as creating renderings, which the engineers regarded as time-consuming and unnecessary at that stage. The generic term ‘sketch’ did not fully describe the requirements and deliverables for both parties. The observation also found that the loosely rendered sketches from the industrial designers were imprecise. For example, the elliptical shapes drawn in perspective became hard to translate into a 3D solid in CAD.

### 2.1.3 Outcome of Interviews & Observations

The interview study had identified 3 problem areas in collaborative design as discussed in section 2.1.1. They were: A) Conflicts in values and principles; B) Differences in design representation and C) Education differences. In addition, the observations revealed the significance of formal and informal meetings, the importance of co-located members and issue of having different interpretations of design representation terminology. Of these, the problem area of design representations was found to be highly significant in both interviews and observations and a decision was made to conduct a further investigation.

## *2.2 Investigating the Use of Design Representations*

The aim of the second stage was to understand the application of design representations employed by industrial designers and engineering designers during NPD. By undertaking an extensive review of the literature, a total of 35 design representations, as well as key design and technical information employed by industrial designers and engineering designers during NPD were mapped out (Table 4).

| | | |
|---|---|---|
| **Sketches** | Idea Sketch<br>Study Sketch<br>Referential Sketch<br>Memory Sketch<br>Coded Sketch | Information Sketch<br>Renderings<br>Inspiration Sketch<br>Prescriptive Sketch |
| **Drawings** | Concept Drawings<br>Presentation Drawings<br>Scenario & Storyboard<br>Diagram<br>Single-View Drawing | Multi-View Drawing<br>General Arrangement Drawing<br>Technical Drawing<br>Technical Illustration |
| **Models** | 3D Sketch Model<br>Design Development Model<br>Appearance Model<br>Functional Concept Model | Concept of Operation Model<br>Production Concept Model<br>Assembly Concept Model<br>Service Concept Model |
| **Prototypes** | Appearance Prototype<br>Alpha Prototype<br>Beta Prototype<br>Pre-Production Prototype<br>Experimental Prototype | System Prototype<br>Final Hardware Prototype<br>Tooling Prototype<br>Off-Tool Prototype |

| | | |
|---|---|---|
| **Design Information** | Design Intent<br>Form & Detail<br>Visual Character<br>Usability and Operation<br>Scenario of Use | Single Views<br>Multi Views<br>Areas of Concern<br>Texture & Surface Finish<br>Colour |
| **Technical Information** | Dimensions<br>Construction<br>Assembly<br>Components | Mechanism<br>Part & Section Profile Lines<br>Exploded Views<br>Material |

Table 4: Types of Representations and Design & Technical Information

The design representations were classified as 4 types of representations (sketches, drawings, models and prototypes) and 2 types of information (design information and technical information) (Pei, *et al*., 2009). The area of design information is concerned with visualisation, aesthetics and usability of the product; while technical information concerned issues such as assembly, mechanism and materials (ibid). This classification was subjected to a series of face-to-face interviews to validate whether the 35 representations and 2 types of information were recognised by both disciplines. The interview structure and process was identical to that of the first stage of interviews and involved 27 participants of which there were 13 industrial designers, 10 engineering designers and 4 project managers. Of the 27 respondents, 6 were academics who were all former industrial design or engineering design practitioners with at least 3 years of work experience.

In the interviews, the first section sought to gather demographic data from the respondents about their background, job scope and projects undertaken. The second section (Figure 1) was structured in the form of a matrix that required the respondent to indicate which design representations were employed during each of the 4 stages of the design process. The purpose was to validate whether the 35 representations were recognised and if they were commonly used by industrial designers and engineering designers at the concept design, concept development, embodiment design and detail design stages of NPD. The matrix shows rows of design representations; while the columns were for the 4 design stages. Recalling a project in mind as an example, the respondents had to decide for each design representation, which stage of the design process it was used in and then tick the respective box. This took approximately 25 minutes to complete.

The interview results are shown in a quantitative format in percentage showing the use of design representations employed during the design process (Table 5). These figures were further translated into bar charts to allow visual comparisons to be made (Table 6).

Name:

Date:

## The Matrix:

**This matrix aims to understand which design representations are used during the design stages of the product development process.**

## Instructions:

**The matrix is divided into 4 rows of design stages and classified into columns of design representations.**

**By going through each stage at a time, tick the appropriate design representation if you have used it during that particular stage.**

| | | | | DESIGN STAGE | | | |
|---|---|---|---|---|---|---|---|
| | | | | CONCEPT DESIGN | CONCEPT DEVELOPMENT | EMBODIMENT DESIGN | DETAIL DESIGN |
| DESIGN REPRESENTATION | SKETCHES | Personal Sketches | Idea Sketch | | | | |
| | | | Study Sketch | | | | |
| | | | Referential Sketch | | | | |
| | | | Memory Sketch | | | | |
| | | Shared Sketches | Information Sketch | | | | |
| | | | Coded Sketch | | | | |
| | | Persuasive Sketches | Inspiration Sketch | | | | |
| | | | Renderings | | | | |
| | | | Prescriptive Sketch | | | | |
| | DRAWINGS | Industrial Design Drawings | Concept Drawings | | | | |
| | | | Presentation Drawings | | | | |
| | | | Scenarios & Storyboards | | | | |
| | | Engineering Design Drawings | General Arrangement Drawings | | | | |
| | | | Technical Drawings | | | | |
| | | | Technical Illustrations | | | | |
| | | | Single-view Drawings | | | | |
| | | | Multi-view Drawings | | | | |
| | | | Tape Drawings | | | | |
| | | | Diagrams | | | | |
| | MODELS | Industrial Design Models | Appearance Models | | | | |
| | | | Design Development Models | | | | |
| | | | Foam Models | | | | |
| | | Engineering Design Models | Functional Concept Models | | | | |
| | | | Production Concept Models | | | | |
| | | | Assembly Concept Models | | | | |
| | | | Concept-of-Operation Models | | | | |
| | | | Service Concept Models | | | | |
| | | | Environment Concept Models | | | | |
| | PROTOTYPES | Industrial Design Prototypes | Appearance Prototype | | | | |
| | | | Alpha Prototype | | | | |
| | | | Beta Prototype | | | | |
| | | | Pre-Production Prototype | | | | |
| | | Engineering Design Prototypes | Experimental Prototype | | | | |
| | | | System Prototype | | | | |
| | | | Final Hardware Prototype | | | | |
| | | | Tooling Prototype | | | | |
| | | | Off-Tool Prototype | | | | |

Figure 1: Matching appropriate representations to the stage of product development

| | | In Percentage of 18 Interviewees | | | | In Percentage of 9 Interviewees | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | % of Industrial Designers | | | | % of Engineering Designers | | | |
| | in % | Concept Design | Concept Development | Embodiment Design | Detail Design | Concept Design | Concept Development | Embodiment Design | Detail Design |
| 1 | Idea Sketch | 94.4 | 27.7 | 16.6 | 16.6 | 77.7 | 11.1 | 0 | 0 |
| 2 | Study Sketch | 72.2 | 33.3 | 16.6 | 16.6 | 88.8 | 0 | 0 | 0 |
| 3 | Referential Sketch | 66.6 | 11.1 | 0 | 0 | 11.1 | 0 | 0 | 0 |
| 4 | Memory Sketch | 72.2 | 16.6 | 5.5 | 5.5 | 0 | 0 | 0 | 0 |
| 5 | Information Sketch | 55.5 | 72.2 | 11.1 | 5.5 | 11.1 | 11.1 | 11.1 | 0 |
| 6 | Coded Sketch | 33.3 | 27.7 | 11.1 | 0 | 11.1 | 0 | 0 | 0 |
| 7 | Inspiration Sketch | 5.5 | 11.1 | 5.5 | 0 | 0 | 0 | 0 | 0 |
| 8 | Renderings | 11.1 | 44.4 | 5.5 | 5.5 | 0 | 11.1 | 0 | 0 |
| 9 | Prescriptive Sketch | 11.1 | 61.1 | 33.3 | 33.3 | 44.4 | 66.6 | 11.1 | 0 |
| 10 | Concept Drawings | 38.8 | 83.3 | 27.7 | 22.2 | 11.1 | 11.1 | 0 | 0 |
| 11 | Presentation Drawings | 16.6 | 55.5 | 22.2 | 22.2 | 0 | 11.1 | 11.1 | 0 |
| 12 | Scenarios & Storyboards | 61.1 | 50 | 0 | 0 | 11.1 | 11.1 | 0 | 0 |
| 13 | General Arrangement Drawings | 0 | 16.6 | 22.2 | 27.7 | 0 | 22.2 | 11.1 | 0 |
| 14 | Technical Drawings | 0 | 5.5 | 22.2 | 16.6 | 11.1 | 0 | 55.5 | 22.2 |
| 15 | Technical Illustrations | 0 | 0 | 11.1 | 16.6 | 11.1 | 0 | 0 | 0 |
| 16 | Single-View Drawings | 16.6 | 33.3 | 22.2 | 16.6 | 0 | 0 | 0 | 0 |
| 17 | Multi-View Drawings | 11.1 | 22.2 | 55.5 | 38.8 | 44.4 | 77.7 | 22.2 | 22.2 |
| 18 | Tape Drawings | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | Diagrams | 11.1 | 22.2 | 5.5 | 5.5 | 22.2 | 0 | 0 | 0 |
| 20 | Appearance Models | 0 | 16.6 | 55.5 | 44.4 | 2 | 0 | 33.3 | 11.1 |
| 21 | Design Development Models | 27.7 | 55.5 | 5.5 | 0 | 1 | 0 | 11.1 | 0 |
| 22 | Foam Models | 22.2 | 61.1 | 27.7 | 5.5 | 0 | 11.1 | 22.2 | 0 |
| 23 | Functional Concept Models | 16.6 | 27.7 | 27.7 | 16.6 | 44.4 | 55.5 | 22.2 | 0 |
| 24 | Production Concept Models | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22.2 |
| 25 | Assembly Concept Models | 0 | 11.1 | 0 | 5.5 | 0 | 0 | 11.1 | 11.1 |
| 26 | Concept of Operation Models | 5.5 | 16.6 | 5.5 | 5.5 | 11.1 | 11.1 | 11.1 | 0 |
| 27 | Service Concept Models | 0 | 5.5 | 5.5 | 0 | 0 | 0 | 0 | 11.1 |
| 28 | Environment Concept Models | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | Appearance Prototype | 5.5 | 5.5 | 27.7 | 61.1 | 0 | 0 | 22.2 | 33.3 |
| 30 | Alpha Prototype | 0 | 0 | 11.1 | 11.1 | 0 | 0 | 11.1 | 11.1 |
| 31 | Beta Prototype | 0 | 0 | 11.1 | 5.5 | 0 | 0 | 11.1 | 0 |
| 32 | Pre-Production Prototype | 0 | 0 | 5.5 | 22.2 | 0 | 0 | 0 | 22.2 |
| 33 | Experimental Prototype | 0 | 5.5 | 5.5 | 5.5 | 33.3 | 33.3 | 22.2 | 11.1 |
| 34 | System Prototype | 0 | 0 | 0 | 5.5 | 0 | 11.1 | 22.2 | 22.2 |
| 35 | Final Hardware Prototype | 0 | 0 | 0 | 5.5 | 0 | 0 | 11.1 | 33.3 |
| 36 | Tooling Prototype | 0 | 0 | 5.5 | 16.6 | 0 | 0 | 11.1 | 22.2 |
| 37 | Off-Tool Prototype | 0 | 0 | 0 | 5.5 | 0 | 0 | 0 | 22.2 |

Table 5: Results from respondents showing use of design representations used during the 4 stages of the design process in percentage

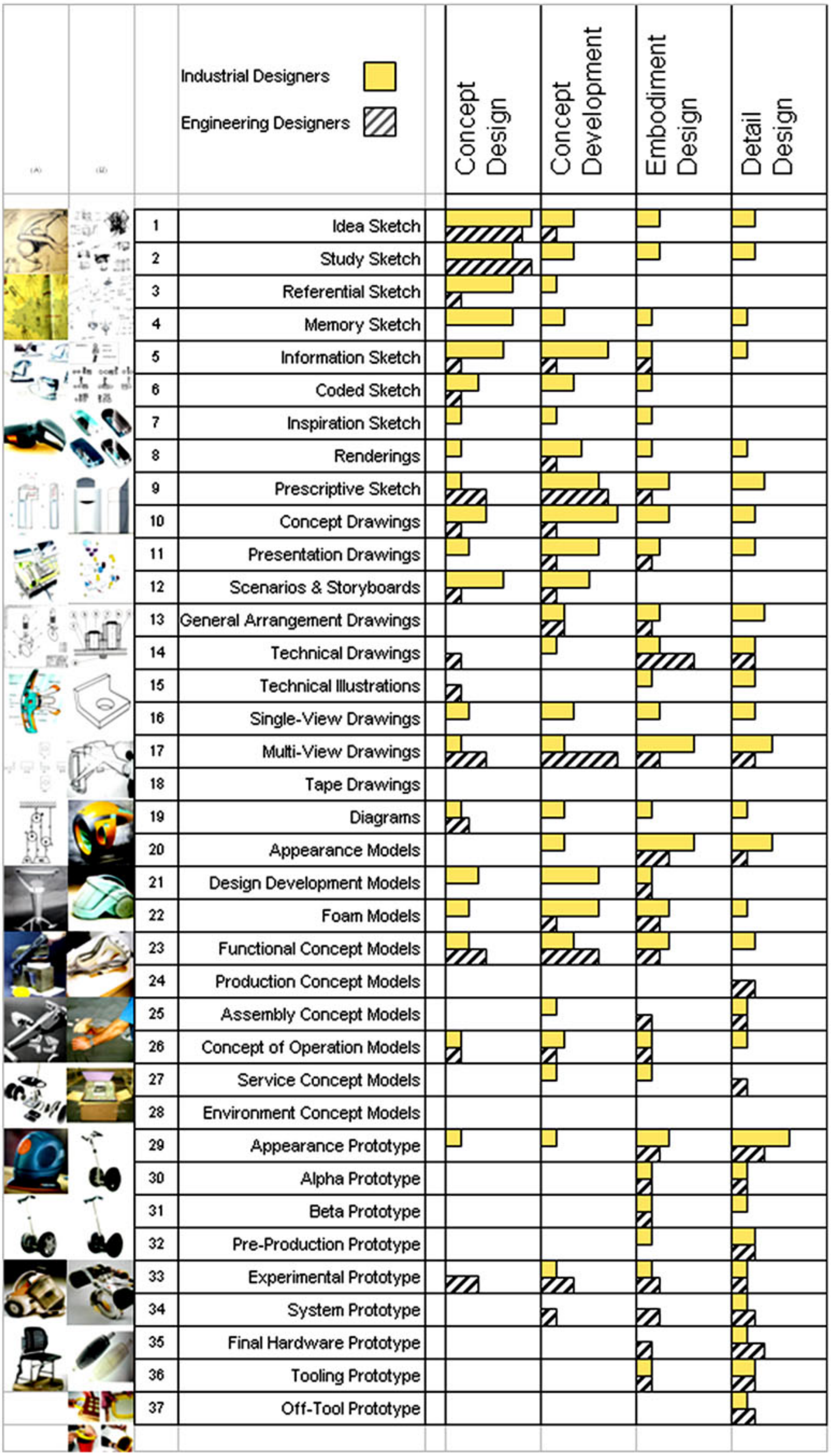



Table 6: Comparative results in a bar chart format

From the results, it can be observed that most design representations were employed by both disciplines, although some were more commonly used by industrial designers and others more commonly used by engineering designers. For example, inspiration sketches were used by industrial designers and were never employed by engineering designers. Similarly, experimental prototypes were more commonly used by engineering designers as compared to industrial designers. A pattern can also be observed whereby the concept design and concept development stages show that most design representations to be used much more by industrial designers than engineering designers. In addition, sketches and drawings were used more commonly by industrial designers throughout the 4 design stages, while the engineering designers only sketched and drew mainly at the concept design and concept development stages. Both industrial designers and engineering designers used models throughout the design process. On the other hand, prototypes were seldom used by the industrial designers and were only employed by engineering designers at the embodiment design and detail design stages.

The interview results are in line with those of Yu and Song, *et al.* (1998) and Buxton (2007) who established that less structured forms of representations such as sketches and models are more commonly used during the concept design stage, while detailed technical drawings and prototypes were more commonly used during the detail design stages of new product development. Similarly, a separate survey also found that industrial designers used sketches more commonly in the task clarification and conceptual stages of design, while simple and complex models were shown to be more frequently used during the later stages of design (Romer, *et al*., 2001). It was also found that results from other researchers investigating the characteristics of some design representations were in line with the interview findings. For instance, McGown, *et al*. (1998) showed that perspective, isometric and axonometric drawings were commonly used by industrial designers in the concept development stages; while in terms of models, Pipes (2007) described that physical models were used by industrial designers commonly in the embodiment stages; while appearance models and appearance prototypes would be more commonly used during the specification stages of the design process (Evans, 2002).

For the last part of the interview, the respondents were asked to complete a matrix (Figure 2) that aimed to investigate the type of design or technical information present within a design representation.

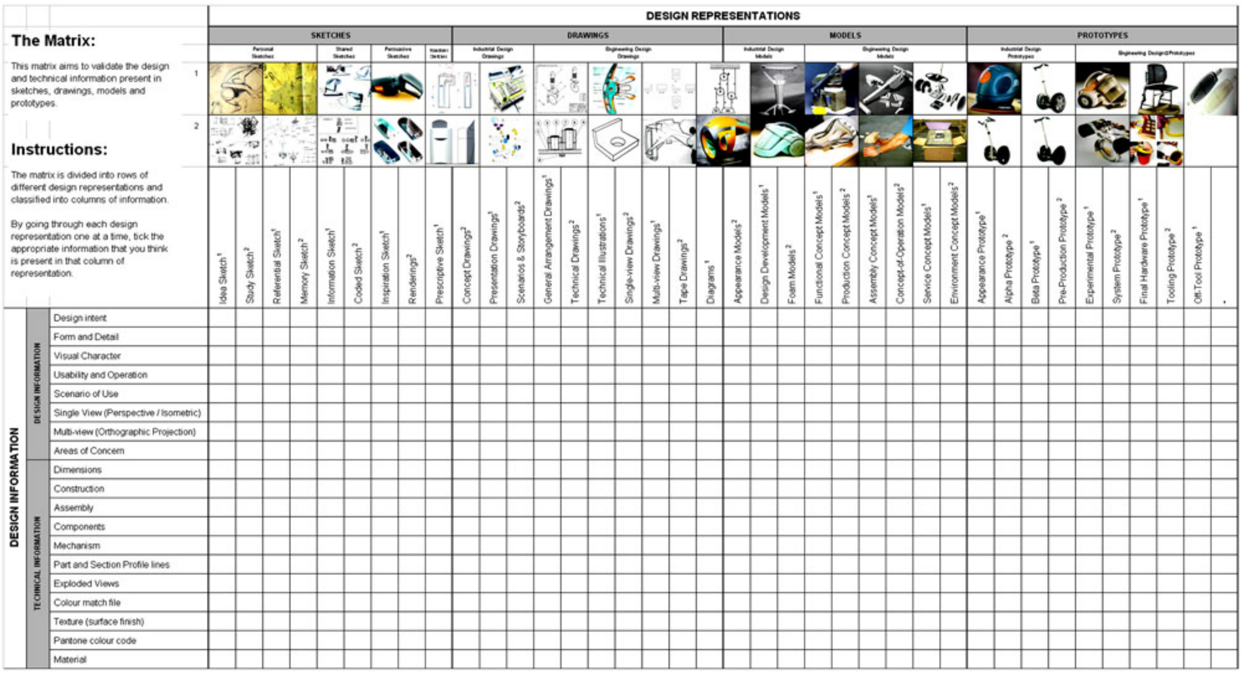
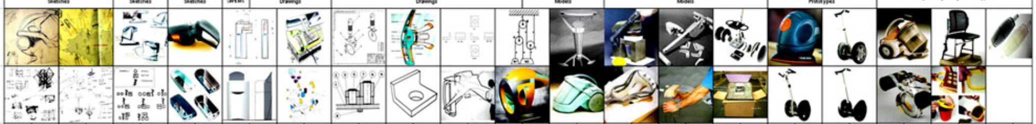



Figure 2: Matching the level of information present in a design representation

In the matrix, the rows contained design and technical information, such as design intent; while the columns comprised of design representations (sketches, drawings, models and prototypes). Working on a representation at a time, each respondent had to identify the design or technical information that might be present within the representation. This took approximately 35 minutes to complete. To allow the respondents to better recognise a representation, a thumbnail image was inserted above each column. All respondents had access to a booklet that provided larger visuals with a detailed description of each representation. The interview results are tabulated as a percentage showing industrial designers (Figure 3) or engineering designers (Figure 4) recognising the level of a design or technical information present within a particular representation.

**Level of Design Information present in Design Representations used by Industrial Designers**

SKETCHES (Personal Sketches, Shared Sketches, Persuasive Sketches, Handover Sketches) · DRAWINGS (Industrial Design Drawings, Engineering Design Drawings) · MODELS (Industrial Design Models, Engineering Design Models) · PROTOTYPES (Industrial Design Prototypes, Engineering Design Prototypes)

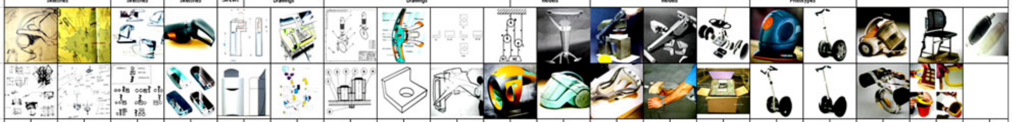


| | in % | Idea Sketch[1] | Study Sketch[2] | Referential Sketch[1] | Memory Sketch[2] | Information Sketch[1] | Coded Sketch[2] | Inspiration Sketch[1] | Renderings[2] | Prescriptive Sketch[1] | Concept Drawings[2] | Presentation Drawings[1] | Scenarios & Storyboards[2] | General Arrangement Drawings[1] | Technical Drawings[2] | Technical Illustrations[1] | Single-view Drawings[2] | Multi-view Drawings[1] | Tape Drawings[2] | Diagrams[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DESIGN INFORMATION | Design intent | 94.4 | 38.8 | 27.7 | 33.3 | 61.1 | 11.1 | 11.1 | 16.6 | 5.5 | 38.8 | 11.1 | | | | | 11.1 | 5.5 | | |
| | Form and Detail | 66.6 | 50 | 22.2 | 38.8 | 88.8 | | 11.1 | 33.3 | 38.8 | 77.7 | 33.3 | | | 5.5 | 11.1 | 16.6 | 16.6 | | |
| | Visual Character | 77.7 | 38.8 | 50 | 38.8 | 66.6 | | 22.2 | 61.1 | 5.5 | 72.2 | 22.2 | 5.5 | | | | | | | |
| | Usability and Operation | 22.2 | 11.1 | 11.1 | 5.5 | 55.5 | 22.2 | | | | 11.1 | 5.5 | 55.5 | | | | | | | 16.6 |
| | Scenario of Use | 11.1 | | 11.1 | 11.1 | 22.2 | | | 5.5 | | 5.5 | 5.5 | 77.7 | | | | | | | |
| | Single View (Perspective / Isometric) | 16.6 | 11.1 | | | 27.7 | | 5.5 | 11.1 | 5.5 | | 33.3 | | | | 5.5 | 44.4 | | | |
| | Multi-view (Orthographic Projection) | | 11.1 | | | | | | | 33.3 | 55.5 | 27.7 | | | 11.1 | | | 66.6 | | |
| | Areas of Concern | 11.1 | 55.5 | 11.1 | 22.2 | 27.7 | 5.5 | | | 5.5 | | | 11.1 | | | | | 5.5 | | 5.5 |
| TECHNICAL INFORMATION | Dimensions | | 5.5 | | | 22.2 | | | | 72.2 | 66.6 | 16.6 | | 27.7 | 33.3 | | | 44.4 | | |
| | Construction | | 5.5 | | | 16.6 | | | | 27.7 | | 27.7 | | 27.7 | 22.2 | 16.6 | | 22.2 | | |
| | Assembly | 5.5 | 11.1 | | 5.5 | 16.6 | | | | 16.6 | | 27.7 | | 22.2 | 22.2 | 16.6 | | 16.6 | | |
| | Components | | 38.8 | 5.5 | 5.5 | 44.4 | 27.7 | | 5.5 | 50 | 50 | 33.3 | | 22.2 | 27.7 | 16.6 | | 22.2 | | 16.6 |
| | Mechanism | 5.5 | 33.3 | | 5.5 | 38.8 | 11.1 | | | 22.2 | 5.5 | 11.1 | | | 11.1 | 5.5 | | 5.5 | | 5.5 |
| | Part and Section Profile lines | | | | | | | | | | | | | 5.5 | 5.5 | | | | | |
| | Exploded Views | | 5.5 | | | 5.5 | | | | 11.1 | | 44.4 | | 5.5 | | | | | | |
| | Colour match file | | | | | 5.5 | | | 5.5 | | 5.5 | | | 5.5 | | | | | | |
| | Texture (surface finish) | 5.5 | | | 5.5 | 72.2 | | 22.2 | 55.5 | | 88.8 | 11.1 | | | | | | | | |
| | Pantone colour code | | | | | 61.1 | | 16.6 | 44.4 | | 72.2 | 5.5 | | | | | | | | |
| | Material | 5.5 | 5.5 | | 5.5 | 77.7 | | 22.2 | 55.5 | 5.5 | 72.2 | 11.1 | | | 22.2 | | | | | |

| | in % | Appearance Models[2] | Design Development Models[1] | Foam Models[2] | Functional Concept Models[1] | Production Concept Models[2] | Assembly Concept Models[1] | Concept-of-Operation Models[2] | Service Concept Models[1] | Environment Concept Models[2] | Appearance Prototype[1] | Alpha Prototype[2] | Beta Prototype[1] | Pre-Production Prototype[2] | Experimental Prototype[1] | System Prototype[2] | Final Hardware Prototype[1] | Tooling Prototype[2] | Off-Tool Prototype[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DESIGN INFORMATION | Design intent | 22.2 | 16.6 | 16.6 | 5.5 | | | 5.5 | | | 50 | 5.5 | | 11.1 | | | | | |
| | Form and Detail | 38.8 | 22.2 | 38.8 | | | | | | | 38.8 | 5.5 | | 5.5 | | | | 5.5 | |
| | Visual Character | 38.8 | 11.1 | 16.6 | 5.5 | | | | | | 50 | 11.1 | 5.5 | 5.5 | | | | | |
| | Usability and Operation | 5.5 | 16.6 | 27.7 | 38.8 | | | 16.6 | | | 11.1 | 11.1 | 11.1 | 5.5 | 5.5 | | | | |
| | Scenario of Use | 5.5 | 5.5 | 11.1 | 11.1 | | | 5.5 | | | 5.5 | | | | | | | | |
| | Single View (Perspective / Isometric) | | | | | | | | | | | | | | | | | | |
| | Multi-view (Orthographic Projection) | | | | | | | | | | | | | | | | | | |
| | Areas of Concern | 5.5 | 33.3 | 33.3 | 5.5 | | | | | | | | | | | | | | |
| TECHNICAL INFORMATION | Dimensions | 33.3 | 11.1 | 16.6 | 11.1 | | | | | | 44.4 | 5.5 | 11.1 | 11.1 | 5.5 | | | 5.5 | 5.5 |
| | Construction | 11.1 | 16.6 | 11.1 | 16.6 | | 5.5 | | | | 33.3 | 16.6 | 16.6 | 16.6 | 5.5 | | | 5.5 | 5.5 |
| | Assembly | 5.5 | 11.1 | 11.1 | 16.6 | 11.1 | 11.1 | | | | 22.2 | 11.1 | 11.1 | 11.1 | | 5.5 | 5.5 | 11.1 | 5.5 |
| | Components | 27.7 | 33.3 | 22.2 | 38.8 | | 11.1 | 11.1 | 5.5 | | 44.4 | 11.1 | 11.1 | 11.1 | 5.5 | 5.5 | 5.5 | 16.6 | 5.5 |
| | Mechanism | 5.5 | 22.2 | 11.1 | 11.1 | | | 5.5 | 5.5 | | 38.8 | 5.5 | 11.1 | 11.1 | 5.5 | 5.5 | 5.5 | 11.1 | 5.5 |
| | Part and Section Profile lines | 5.5 | 5.5 | 5.5 | | | | | | | 11.1 | | | | | | | | |
| | Exploded Views | | | | | | | | | | | | | | | | | | |
| | Colour match file | | | | | | | | | | 5.5 | 5.5 | 5.5 | 5.5 | | | | 5.5 | 5.5 |
| | Texture (surface finish) | 50 | 5.5 | | | | | | | | 61.1 | 11.1 | 11.1 | 11.1 | | | | 11.1 | 5.5 |
| | Pantone colour code | 38.8 | 5.5 | | | | | | | | 50 | 5.5 | 5.5 | 5.5 | | | | 5.5 | |
| | Material | 44.4 | 5.5 | | | | | | | | 50 | 5.5 | 5.5 | 5.5 | | | 5.5 | 5.5 | |

Figure 3: Level of Design Information present in Design Representations used by Industrial Designers (in percentage)

**Level of Design Information present in Design Representations used by Engineering Designers**



| | in % | Idea Sketch[1] | Study Sketch[2] | Referential Sketch[1] | Memory Sketch[2] | Information Sketch[1] | Coded Sketch[2] | Inspiration Sketch[1] | Renderings[2] | Prescriptive Sketch[1] | Concept Drawings[2] | Presentation Drawings[1] | Scenarios & Storyboards[2] | General Arrangement Drawings[1] | Technical Drawings[2] | Technical Illustrations[1] | Single-view Drawings[2] | Multi-view Drawings[1] | Tape Drawings[2] | Diagrams[1] | Appearance Models[2] | Design Development Models[1] | Foam Models[2] | Functional Concept Models[1] | Production Concept Models[2] | Assembly Concept Models[1] | Concept-of-Operation Models[2] | Service Concept Models[1] | Environment Concept Models[2] | Appearance Prototype[1] | Alpha Prototype[2] | Beta Prototype[1] | Pre-Production Prototype[2] | Experimental Prototype[1] | System Prototype[2] | Final Hardware Prototype[1] | Tooling Prototype[2] | Off-Tool Prototype[1] | . |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SKETCHES | | | | | | | | | DRAWINGS | | | | | | | | | | MODELS | | | | | | | | | PROTOTYPES | | | | | | | | | |
| | | Personal Sketches | | | | Shared Sketches | | Persuasive Sketches | | [illegible] Sketches | Industrial Design Drawings | | | Engineering Design Drawings | | | | | | | Industrial Design Models | | Engineering Design Models | | | | | | | Industrial Design Prototypes | | | | Engineering Design Prototypes | | | | | |
| DESIGN INFORMATION | Design intent | 22.2 | 22.2 | 11.1 | | 11.1 | | | | | | | | | | | | | | 11.1 | 11.1 | 11.1 | 11.1 | 11.1 | | | | | | 33.3 | | | | | | | | | |
| | Form and Detail | 33.3 | 22.2 | | | 11.1 | | | | 11.1 | | | | | | | | 11.1 | | | 22.2 | 11.1 | 11.1 | | | | | | | 33.3 | | | | | | | | 11.1 | |
| | Visual Character | 22.2 | | | | 11.1 | | | | | | | | | | | | | | | 33.3 | | | | | | | | | 33.3 | | | | | | | | | |
| | Usability and Operation | 33.3 | 11.1 | | | 11.1 | | | | | 11.1 | | 22.2 | | | | | | | 11.1 | | 11.1 | 22.2 | 77.7 | | | 33.3 | | | | | | | 22.2 | | | | | |
| | Scenario of Use | 11.1 | 11.1 | | | 11.1 | | | | | 11.1 | | 22.2 | | | | | | | | | | | 22.2 | | | 22.2 | | | | | | | | | | | | |
| | Single View (Perspective / Isometric) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Multi-view (Orthographic Projection) | | 11.1 | | | | | | | 11.1 | 11.1 | | | 11.1 | 11.1 | | | 44.4 | | | | | | | | | | | | | | | | | | | | | |
| | Areas of Concern | 11.1 | 88.8 | | | | | | | | | | | | | | | | | 11.1 | | 11.1 | 33.3 | 11.1 | | | | | | | 11.1 | | | 11.1 | 11.1 | 22.2 | 11.1 | | |
| TECHNICAL INFORMATION | Dimensions | | 44.4 | | | 11.1 | | | | 77.7 | 22.2 | | | 33.3 | 66.6 | | | 88.8 | | | 11.1 | | | 11.1 | 11.1 | | | | | 33.3 | 22.2 | 11.1 | 22.2 | 11.1 | 11.1 | 33.3 | 22.2 | 22.2 | |
| | Construction | 22.2 | 66.6 | | | 11.1 | 11.1 | | | 33.3 | 11.1 | | | 33.3 | 66.6 | | | 55.5 | | | | | 11.1 | 11.1 | 22.2 | 11.1 | | | | 33.3 | 11.1 | 11.1 | 11.1 | 22.2 | 11.1 | 22.2 | 11.1 | 11.1 | |
| | Assembly | 22.2 | 66.6 | | | 11.1 | 11.1 | | | 44.4 | | | | 33.3 | 44.4 | 11.1 | | 55.5 | | | 22.2 | 11.1 | 11.1 | 22.2 | 22.2 | 11.1 | | 11.1 | | 33.3 | 11.1 | 11.1 | 11.1 | 22.2 | 11.1 | 22.2 | 11.1 | 11.1 | |
| | Components | 44.4 | 66.6 | 11.1 | | 33.3 | 11.1 | | | 66.6 | 22.2 | | | 33.3 | 55.5 | 11.1 | | 66.6 | | | 22.2 | 11.1 | 22.2 | 77.7 | | | 22.2 | | | 44.4 | 22.2 | 11.1 | 22.2 | 44.4 | 33.3 | 33.3 | 22.2 | 22.2 | |
| | Mechanism | 44.4 | 66.6 | | | 33.3 | 11.1 | | | 44.4 | | | | 22.2 | 44.4 | | | 22.2 | | | 11.1 | | | 77.7 | | | 22.2 | | | 33.3 | 11.1 | 11.1 | 11.1 | 44.4 | 33.3 | 33.3 | 22.2 | 22.2 | |
| | Part and Section Profile lines | | | | | | | | | | | | | | 11.1 | | | | | | | | | | | | | | | 11.1 | | | | | | | | | |
| | Exploded Views | | | | | | | | | | | | | | 11.1 | 11.1 | | | | | | | | | | | | | | | | | | | | | | | |
| | Colour match file | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Texture (surface finish) | | | | | 33.3 | | | | | 22.2 | | | | | 11.1 | | | | | 33.3 | | | | | | | | | 44.4 | 22.2 | 11.1 | 22.2 | | | 11.1 | 11.1 | 22.2 | |
| | Pantone colour code | | | | | 33.3 | | | | | 22.2 | | | | | 11.1 | | | | | 33.3 | | | | | | | | | 44.4 | 22.2 | 11.1 | 22.2 | | | 11.1 | 11.1 | 22.2 | |
| | Material | | 11.1 | | | 33.3 | | | | 11.1 | 22.2 | | | 11.1 | 33.3 | 11.1 | | | | | 33.3 | | | | | | | | | 44.4 | 22.2 | 11.1 | 22.2 | | | 11.1 | 11.1 | 22.2 | |

Figure 4: Level of Design Information present in Design Representations used by Engineering Designers (in percentage)

From the analysis, a pattern was observed where in general, sketches, drawings and models provided a good balance of design and technical information, while prototypes were mainly concerned with technical information. It was also found that design information is more commonly used by industrial designers as compared to engineering designers. Conversely, technical information has been more commonly used by engineering designers as compared to industrial designers, as expected.

In summary, the interviews determined the various design representations employed by industrial designers and engineering designers during the 4 phases of NPD, showing that some were more commonly employed by industrial designers or engineering designers. The findings revealed differences in the level of design and technical information present within a visual design representation when employed by both disciplines. It was found that sketches, drawings and models provided design and technical information, while prototypes were mainly concerned with technical information. It was also observed that design information was more associated with industrial designers as compared to engineering designers who were seen to be more concerned with technical information. With these in mind, the following section discusses the tool development, justifying its need and covering issues relevant to the formulation of the design aid.

## 4. Tool Development

The purpose of the tool is to provide a comprehensive resource that would support and enhance understanding between industrial designers and engineering designers. Although collaboration mechanisms such as co-location, personnel movement, informal social systems and organisational structures can be employed (Griffin and Hauser, 1996), they require physical changes to the environment. The proposed design tool would not require modifications to the workspace and would be a stand-alone product.

For the development of the design tool, several factors were used to determine the tool specification. According to Saddler (2001), the industrial design profession has representations that are ill-defined, imprecise and lack in communicative power. In addition, communication could be improved by having a common understanding of shared definitions (Matthew, 1997). Therefore, the primary feature of the design tool serves to clarify the terminology of design representations and to act as an effective means of communicating these shared definitions.

Taking a step further, the design aid should provide a common vocabulary through the use of standardised communicative codes and language (Persson and Warell, 2003). Translating this as a design specification, the tool should be able to communicate the meanings accurately by reaching the audience through a suitable medium (Chiu, 2002). To meet this requirement, several physical formats were developed, including matrices, flowcharts, wheel diagrams and Rolodex systems. Digital formats were also considered but this meant that users would need to have constant access to a computer and it would be impractical to carry a laptop at all times. While personal digital assistants, tablets or mobile phones presented more portable options, the dissimilar operating systems, short battery life and small screens would create additional problems for information retrieval. In addition, Wi-Fi or internet-based tools would be limited to subscribers or connectivity.

Following an appraisal by the authors, the card format was selected because its tangible format and ease of portability would encourage immediate interaction between users. The cards allowed instant access to information and could be shared and distributed quickly among members, thereby facilitating socialisation and shared knowledge. It is envisaged that the cards would be used by industrial design and engineering design practitioners as a portable tool that could be carried around as a reference guide or kept as an office resource or a learning tool.

To facilitate and enhance access to the information, a total of 114 cards were colour-coded, with the red pack (57 cards) giving information on industrial design practice and the blue pack (57 cards) on engineering design practice. The 57 cards of each pack consists of 4 cards describing the 4 design stages of NPD (Set 1), 10 design information cards and 8 technical information cards (Set 2), and 35 design representations (Set 3) which are now discussed.

Set 1: Design Stages

This set consists of 4 cards from each coloured pack (red for industrial designers, blue for engineering designers) that describe the 4 design stages of NPD (Figure 5).


Figure 5: Set 1 – Key stages of the NPD process

The front face provides the definition of a design stage which was derived from the literature review. The bar graphs and numbers on the rear show the popularity of use by practitioners for a particular design representation during each stage of NPD. The popularity is given as a percentage that was generated from responses by the practitioners interviewed during the second empirical research.

Set 2: Design & Technical Information

The second set consists of 10 cards showing design information and 8 cards showing technical information used by industrial designers and engineering designers (Figure 6).


Figure 6: Set 2 – Key design and technical information

The front face identifies if the card is for design or technical information. The rear illustrates the popularity of use for design representations via bar graphs and numbers obtained from the second round of empirical research. The categorisation of design information is based on data relating to industrial design decision making, such as form and detail, visual character and colour. Technical information includes data on features such as mechanisms, assembly and construction.

Set 3: Design Representations

The third set (Figure 7) represents key design representations used by industrial designers and engineering designers during NPD.


Figure 7: Set 3 – Design Representations

The front face provides the name, definition and a visual example of the representation and the rear shows the associated design and technical information. Details on the popularity of use during each design stage is also provided.

There is no pre-defined way of using the card system. It is a resource that provides information on the nature of the design process and relevant information required. It does this from both an industrial design and engineering design perspective, providing data on the different ways that each group employs design representations during NPD. To illustrate an application, a scenario might involve an engineering designer wanting to know the most effective design representation that the industrial designer could supply / produce to communicate a product proposal's 'form and detail'. By selecting the red industrial design pack and looking at the form and detail card (Figure 8) the popularity of use on the reverse face indicates that the most effective representation would be the information sketch, as 90% of the industrial designers surveyed used this to communicate this attribute.

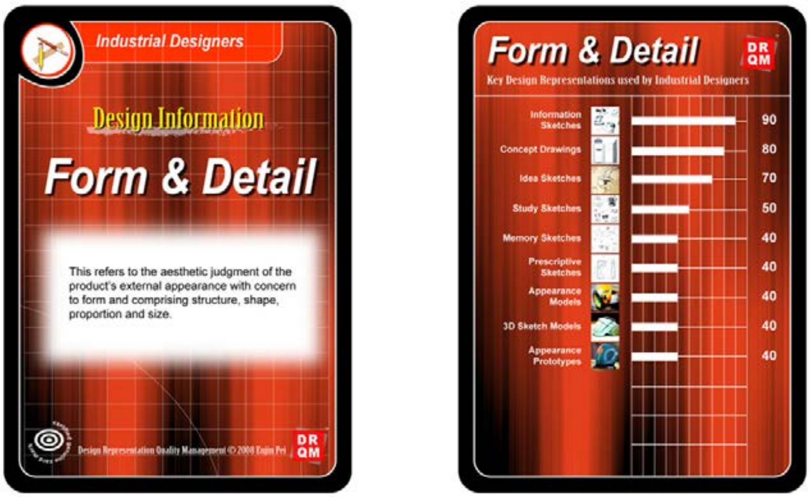



Figure 8: Form and detail card from the industrial design set

## 5. Appraisal and Validation

### *5.1 Pilot Study*

Having defined the draft design aid, the appraisal process commenced with a pilot study that involved interviews with 10 design practitioners. Feedback indicated that a numerical referencing system would support faster access to information and a larger card format (ISO B8 size of 62×88 mm) would improve readability. Other improvements include a simplified layout with less text and larger images. The background was also redesigned for less visual clutter. The revised design is shown in Figure 9.


Figure 9: Improved version of the cards after pilot appraisal

### *5.2 Validation*

Having integrated several improvements, the validation was undertaken through a 3-phase strategy. The first phase utilised semi-structured interviews asking final year industrial design and engineering design undergraduates who had worked together on an industrial project. The second phase involved the same questions with experienced practitioners to obtain feedback on the format and the system. The third phase involved the use of observations to study how the cards would be used during the design of a consumer product at an industrial design consultancy. A design diary was developed to record end-of-the-day thoughts and activities, as well as details of where the cards were used and why they were used.

The first phase of the validation involved 4 industrial design and 14 engineering design final year undergraduates who had worked together for an academic semester (4 months) on an industry-based project. Due to the academic curriculum, it was not feasible to introduce a new design exercise. A decision was made to conduct an interview to find whether the tool could have improved collaboration. As the project was organised by the engineering department, there were more engineering design student participants. The cards were first introduced to the students and they were given an hour to familiarise with the design tool. Subsequently, the industrial design and engineering design students had the opportunity to regroup and discuss if their collaboration might have been better enhanced through the use of the cards.

The interviews comprised of 10 questions relating to the content and format of the design tool as shown in Table 7. The respondents could either agree or disagree according to a 5-point Likert scale: excellent, good, neutral, poor, very poor (Gadsden, 2006). The average Likert scores were tabulated into a matrix and then represented as pie-charts. This method of calculating average scores has been considered to be appropriate when dealing with Likert scales (Engelbrektsson and Soderman, 2004). To improve reliability, the results were rechecked with the respondents after each session.

| **Research-specific questions** |
|---|
| 1. How do you generally feel about the card format? |
| 2. How do you feel about the physical size of the cards? |
| 3. How would you rate the clarity and understandability of the textual content and pictorial data? |
| 4. How would you rate the ability of the cards to provide you with an enhanced understanding and clearer definition of design representations? |
| 5. How do you feel about the effectiveness of the cards to provide a common understanding of design representations between IDs and EDs? |
| 6. How would you rate the use of bar charts that show key design and technical information? |
| 7. How would you rate the ability of the cards to help you identify the representation most commonly used during different stages of the design process? |
| 8. How do you feel about the ability of the cards to foster enhanced collaboration between IDs and EDs? |
| 9. How do you feel about the ability of the cards to improve design collaboration between yourself and other industrial designers / engineering designers? |
| 10. Would you have any suggestions or additional feedback to help us improve the cards? |

Table 7: Research-specific questions

All industrial design students (100%) and 92.9% of engineering design students gave a good and excellent feedback regarding the physical format of the cards. All industrial design students and 85.5% of engineering design students felt that the tool would provide an enhanced understanding of design representations. 66.7% of industrial design students and 64.3% of the engineering design students felt that the cards would be effective in creating common understanding of design representations. While some students found it hard to search for the right cards, it was argued that if a systematic approach was followed, the required cards could be quickly identified. Most importantly, all industrial design students and 85.8% of engineering design students felt that the tool would have helped to foster enhanced collaboration.

The second part of the interviews involved the same 10 questions with 43 practitioners from 15 organisations with an average professional experience of 10 years. Reliability was maximised by surveying a mix of industrial design and engineering design managers and non-managers from small and large multi-national design consultancies. When asked about the physical format, 86.4% of industrial designers and 89.5% of engineering designers gave a good and excellent rating. Similarly, 86.4% of the industrial designers and 89.5% of the engineering designers agreed that the tool would provide an enhanced understanding and clearer definition of design representations. The practitioners (industrial designers 86.4%; engineering designers 84.2%) also agreed that the system would create a common understanding of design representations. Some respondents requested more information to be included, such as the tools needed for creating a certain design representation. This was not implemented as it was not part of the criteria.

When asked if the system would foster enhanced collaboration, 68.2% of industrial designers gave a good and excellent rating and 27.3% were neutral. 63.2% of the engineering designers gave a good and excellent rating and 36.8% were neutral. A small number of participants had claimed that experienced practitioners did not need these cards. However, it was argued by the authors that these cards would not be solely used by senior practitioners but for all levels of users. In summary, the results indicated that a high percentage of interviewees were confident that the tool would provide a common ground when using design representations, thereby contributing to enhanced collaboration.

The third phase of the validation covered a period of 3 weeks that tested the tool within a small design consultancy with 10 employees. It involved the design of a consumer product that started at the concept generation stage and ended at the embodiment design stage. Observing how the tool would be used within a commercial context was clearly useful as the authors could not predict exactly how the tool would be received by the users during practice. To maximise the reliability of the findings, the observations were conducted within the normal work environment. Recordings made through a design diary at the end of the day minimised disruptions to work. To obtain holistic feedback, the industrial designers, engineering designers and team leader were observed and interviewed at the end of each day. The design diary approach as employed by Pedgley (2007) captured and enabled analysis of activities on a daily basis and allowed events to be described in a chronological order (Figure 10).

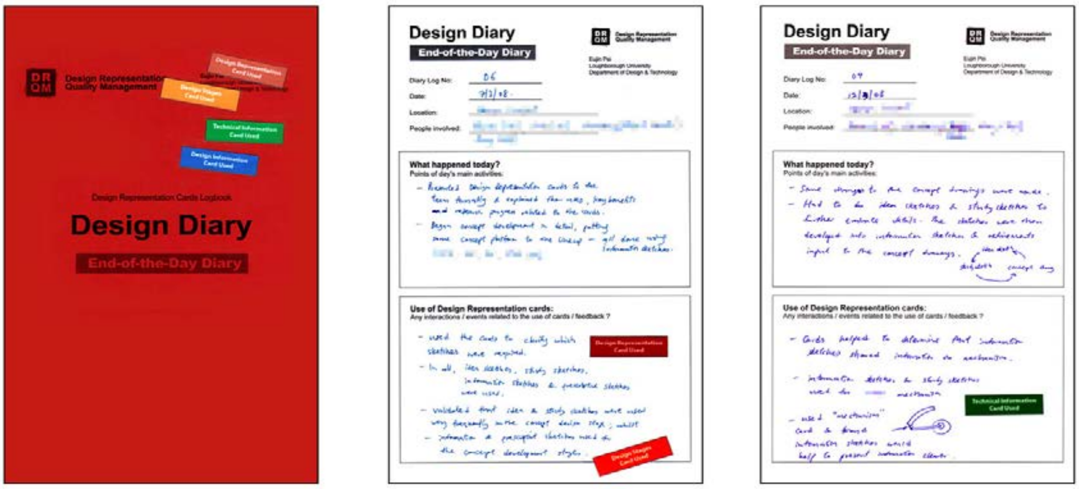



Figure 10: The design diary used to record findings

During the observations, it was noted that the cards were useful as a clarification tool during the design process. On commencement of the third week, it became apparent that both industrial designers and engineering designers used identical keywords that had been learnt from the cards, thereby minimising the potential for misunderstanding. For example, the engineering designer would now request for a more specific type of representation as compared to using ‘sketch’ as a generic term. This allowed for more precise and relevant representations to be delivered. Similarly, when there was a need for a specific type of technical information, the industrial designer could now refer to the cards to find the exact data that was required. The findings from the observations reinforced results from the practitioner interviews and provided further evidence of the potential for the tool to foster collaboration in a multi-disciplinary environment. From the validation, it was found that most participants gave an excellent and good rating for the design tool. However, the results should be considered in the light of study constraints that was limited to 65 respondents. Therefore generalisation of the findings should be made with caution. Also, as the tool was tested within a relatively short time frame and this should be noted.

## 6. Summary

### *6.1 Discussion*

The aim of this research was to develop a collaborative design tool for use by industrial designers and engineering designers. To achieve this, a literature review was undertaken to understand the working relationship between the two disciplines in NPD. Following this, empirical research through interviews and observations outlined three problem areas: conflicts in values and principles; differences in education; and differences in representational tools and methods. The latter was chosen because the problem area of design representations was found to be highly significant.

In looking at bridging differences in design representations, a taxonomy comprising 35 forms of sketches, drawings, models and prototypes was generated. A second stage of empirical research was conducted to establish the popularity of each representation and the type of design / technical information that industrial designers and engineering designers communicated with. The information was indexed into a design tool in the form of cards that would enable the 2 disciplines to gain joint understanding and create shared knowledge when using visual design representations. When asked in the validation study if the system would foster collaboration, 68.2% of industrial designers and 63.2% of the engineering designers gave a good and excellent rating, indicating that the system could play a significant role towards the support of multi-disciplinary teamwork. However, the results should be considered in the light of study constraints that were limited to 65 respondents and that the tool was tested only within a short time frame.

### *6.2 Conclusions*

Design representations are an integral component of NPD as they support innovation through the communication of design ideas and intent. The fact that communication, design representation and collaboration are closely linked means that the use of the design aid can enhance professional practice by presenting itself as a language platform to standardise vocabulary, facilitating social networks and enhancing understanding between the partners. The context where the tool can be used is not limited to industrial designers and engineering designers, but has the potential for use by other stakeholders, including marketing and production engineering. Additionally, the tool has a prospective application as a teaching and learning tool in design education.

Whilst the formalisation embodied in the tool might be seen as introducing rules and procedures which, at times may have a negative impact (Burns and Stalker, 1961), the authors believe that a focused system would minimise misinterpretation and lead to more accurate communication. By including key design and technical information, the tool serves as a decision-making guide and helps identify representations used during design stages. It also allows users to be aware of each others' working practice and aids the coordination of actions, task management and the anticipation of actions by others (Gutwin and Greenberg, 1996). Through the use of the proposed tool, inter-disciplinary teams are able to develop a shared language to communicate effectively. By simplifying processes and communication, interaction becomes easier, operations are quickened and parallel processing achieved. Users are able to eliminate unnecessary design representations, saving time, accelerating NPD and achieving a common ground between industrial designers and engineering designers.

Future research would include testing the tool for a longer duration and involving a larger sample of participants. This would help establish a more comprehensive and thorough feedback before being developed for volume production and its launch as a commercial product.

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## 8. List of Figure Captions



## 9. List of Table Captions