

Faculty of Art, Design and Architecture
Department of Design

The Use of Design Tools in Industrial Design Practice

By

James Andrew Self

A Doctoral Thesis

Submitted in partial fulfilment of the requirements
for the award of

Doctor of Philosophy
Kingston University London

© James Andrew Self

September, 2011

Abstract

The industrial designer employs a wide variety of design tools to externalise, develop, propose and specify design solutions. This use of tools locates within a rich set of co-dependent relationships: the character and affordance of individual tools; a designer's expertise in tool use; the influence of the pragmatic requirements of the design process; working culture; and the designer's idiosyncratic use of tools. The research addresses a need to continue to develop an understanding of how design activity is influenced by the use of various established and emergent digital, conventional and hybrid tools and the designer's attitude towards tool use.

An adapted model of activity theory was employed together with a taxonomy of design tools and a description of Universal Tool Characteristics (UTCs) to explore the designer's use of tools during practice. Survey studies of two sample groups, design practitioners and design students, were conducted. The study revealed significant differences, between the practitioners and students, in attitudes towards the UTCs of some design tools. In a second phase of research semi-structured interviews were undertaken to further investigate relationships between individual design tools and the practitioner's influence on tool use. Survey and interview findings generated a new framework to comprehensively describe design tool use during industrial design practice. The work was translated into a digital tool (IDsite) that supports less experienced designers in developing awareness of the relationships between tool use and the design process.

Findings indicated the ways in which designer attitudes are a reflection of existing approaches to practice. Student designers tended towards a more constrained, convergent approach that can lead to earlier fixation and the crystallisation of concept ideas. Experienced practitioners tend to take a more explorative, divergent and often iterative approach to design work, allowing their design activity to remain open to suggestion and revision. Evidence of this was made explicit through more negative attitudes from students towards those UTCs associated with divergent conceptual design: lateral transformations between design ideas; ambiguity in design embodiment; reflection-in-action during design embodiments. These pre-existing approaches to studio practice are compounded through the use of certain design tools (sketch modelling, 3D printing 3D CAD). The research concludes that awareness of, and engagement with, the relationships between tool use and the dynamic requirements of

the industrial design process have a profound influence on attitudes towards design activity, tool selection and use. The research makes explicit some of these differences and how they critically inform the designer's studio practice.

Key Words

Industrial design, design tools, design embodiment, design activity, industrial design process, characteristics

The Author

James Self has a bachelor's degree in Model Design and a master's qualification in Digital Modelling with Rapid Prototyping, both awarded at the University of Hertfordshire. Between being awarded his degrees he worked as a freelance professional model maker, both in the UK and abroad. His work involved the physical embodiment of design intentions as models and prototypes for the communication and development of design ideas at various stages in their development. After seven years experience in practice his Masters dissertation compared the use of conventional workshop processes in the modelling of design intentionality with emergent and established digital (rapid prototyping) and hybrid (haptic devices) soft/hardware and systems.

James enrolled at Kingston University to undertake research on design activity and tool use reported in this thesis.

Acknowledgements

Although this doctoral study has been both challenging and demanding, it has also been rewarding. Above all it has given me an understanding of how little I know, and how much there is to learn.

My appreciation is extended to all the design practitioners, students and educators that took the time to be a part of this research.

I would like to offer my heartfelt thanks to my supervisors Professor Hilary Dalke and Dr Mark Evans who have provided both academic and pastoral support through the many highs as well as the lows.

My final thanks and deepest gratitude are reserved for my wife, Shin Jeong Ae, for her patient support and her unfailing encouragement.

This thesis is dedicated to Shin Jeong Ae

Acronyms

2D	Two-dimensional
3D	Three-dimensional
CAD	Computer Aided Design
ID	Industrial Design
NPD	New product development
RP	Rapid prototyping

Key Terms

3 Stage Model of Design Process (Concept, Development, Detail Design)

Activity Theory

Analog Design Tools

Convergent Design Activity

Design Activity

Design Embodiment

Design Practice

Digital Design Tools

Divergent Design Activity

Hybrid Design Tools

Lateral Transformation

Level of Ambiguity

Level of Commitment

Level of Detail

Mode of Communication

Model of Design Activity and Tool Use

Reflection-in-Action

Taxonomy of Design Tools

Themes of Discussion

Tool Use

Topics of Conversation

Transformational Ability

Universal Tool Characteristics (UTCs)

Vertical Transformation

Contents

Abstract	3
Key Words.....	4
The Author.....	5
Acknowledgements	6
Acronyms	7
Key Terms.....	7
List of Figures & Tables.....	15
Chapter 1: Introduction	26
1.1 Overview: Industrial Design Tools and Design Activity.....	26
1.2 Research Scope and Audience	29
1.3 Research Aim, Objectives & Questions.....	29
1.4 Research Methodology.....	31
1.5 7 Phase Research Methodology and Thesis Structure.....	32
Chapter 2: Design and Industrial Design Practice.....	35
Introduction.....	35
2.1 Design	36
2.2 Design as Human Activity.....	36
2.3. Design Research.....	38
2.4. Research in Design Practice	39
2.5 A History of Industrial Design	41
2.6 Industrial Design Practice.....	43
2.7. Industrial Design as Embodiment of Intentions	45
2.8. Art, Creativity and Industrial Design	48
2.9. Engineering and Industrial Design.....	49
2.10 A Working Definition of Industrial Design	50
2.11. NPD and Industrial Design	51
2.11.1 Staged Models of NPD	51
2.12.1. Staged Models of NPD with Iteration.....	54

2.12.2 Integrated Models of NPD	59
2.13 Modelling NPD and Industrial Design	62
2.14 Three Phases of Design Process	65
2.14.1 Concept Design	65
2.14.2 Development Design	70
2.14.3 Detail Design	74
Chapter Summary	78
Chapter 3: Tools of Design Embodiment and Design Activity	80
Introduction.....	80
3.1 Tools of Design Embodiment and the Design Process	81
3.2 Tools of Embodiment and Reflection-in-Action.....	83
3.3 The Designer and the Character of Design Tools	86
3.4 Analog, Digital and Hybrid Tools	91
3.4.1 Analog Tools	92
3.4.2 Digital Tools.....	96
3.4.3 Hybrid Tools	99
3.5 Activity Theory: An Introduction.....	104
3.6 Activity Theory and Design.....	106
3.7 Activity Theory and the Designer.....	106
3.7 Activity Theory and the Industrial Design Process	108
3.8 Activity Theory and Design Tools	110
3.9 Modelling Design Activity and Tool Use	112
Chapter Summary	116
Chapter 4: Taxonomy of Design Tools	117
Introduction.....	117
4.1 Existing Design Tool Taxonomies	117
4.1.2 Pei et al's Taxonomy	118
4.1.3 Stolterman et al's Taxonomy	119
4.1.4 Pipes' Classification of Design Drawings.....	121
4.1.5 Olofsson & Sjolen's Classification of Sketching.....	122
4.1.6 Slack's Description of Tools	123
4.2 The Taxonomy of Design Tools.....	124
4.2.1 3 Stages of Design Practice	127

4.2.2 Division around 3 Stages in Design Practice	128
4.2.3 Classification of 10 Design Tools	129
4.2.4 Classification of 10 Design Embodiments	130
4.3 Tools Used During Concept Design	131
4.3.1 Hand Sketching	131
4.3.2 Digital Sketching	133
4.3.3 Sketch Modelling	134
4.3.4 3D Printing	137
4.4 Tools Classified under Development Design	138
4.4.1 Digital Graphics Tools	139
4.4.2 Conventional Graphics Tools	141
4.4.3 3D CAD Tools	143
4.5 Tools Used During Detail Design Practice.....	145
4.5.1 2D CAD Tools	146
4.5.2 Rapid Prototyping Tools	147
4.5.3 Conventional Model Making Tools	148
4.6 Discussion	150
Chapter Summary	150
Chapter 5: Universal Characteristics of Design Tools.....	152
Introduction.....	152
5.1 Tool Characteristics: Opportunity for Investigation	153
5.2 UTCs: An Overview	154
5.3 The UTCs of Sketching Tools.....	156
5.4 Description of 5 UTCs	156
5.4.1 Mode of Communication.....	157
5.4.2 Level of Ambiguity	159
5.4.3 Transformational Ability	162
5.4.4 Level of Detail.....	165
5.4.5 Level of Commitment.....	167
Chapter Summary	169
Chapter 6: Research Methods.....	170
Introduction.....	170
6.1 Research Questions	171

6.2 Research Methods: Context and justification	172
6.3 Informing Research Methods: Activity Theory, Taxonomy & UTCs	174
6.4 Survey Study	175
6.4.1 Survey Samples	175
6.4.2 Practitioner Sample	176
6.4.3 Student Sample	178
6.4.4 Survey Design & Process	178
6.4.5 Survey Data Coding and Analysis	183
6.4.6 Pilot Survey: Non-response and Respondent Fatigue	183
6.5 Interview Study	189
6.5.1 Sample Group	189
6.5.2 Interview Design & Process	191
6.6 Interview Data Coding and Analysis	194
6.6.1 First Level Coding: Design Tool Nodes	197
6.6.2 Second Level Coding: Themes of Discussion Nodes	198
6.6.3 Third Level Coding: Topics of Conversation Nodes	200
Chapter Summary	203
Chapter 7: Survey Results	204
Introduction	204
7.1 Results: Design Tool and Design Embodiment	205
7.3.1 Hand Sketching	206
7.3.2 Digital Sketching Tools	210
7.3.3 Sketch Modelling Tools	214
7.3.4 3D Printing Tools	218
7.3.5 Digital Graphics Tools	222
7.3.6 Conventional Graphics Tools	226
7.3.7 3D CAD Tools	230
7.3.8 Model Making	235
7.3.9 Rapid Prototyping Tools	239
7.3.10 2D CAD Tools	243
7.4 Designer Influence and Tool use	248
7.4.1 Hand Sketching Tools	250
7.4.2 Digital Sketching Tools	251
7.4.3 Sketch Modelling Tools	253
7.4.4 3D Printing Tools	257

7.4.4 Digital Graphics Tools	260
7.4.5 Conventional Graphics Tools	261
7.4.6 3D CAD Tools	264
7.4.7 Conventional Model Making Tools	267
7.4.7 Rapid Prototyping Tools	269
7.4.7 2D CAD Tools	272
7.5 The Designer and Design Embodiment.....	273
7.5.1 Ambiguous Embodiment	274
7.5.2 Lateral Transformations.....	275
7.5.3 Vertical Transformations.....	276
7.5.4 Reflection-in-Action	277
7.5.5 Relationships between UTCs	278
7.6 Discussion	280
Chapter Summary	283
Chapter 8: Results of Interview Study.....	285
Introduction.....	285
8.1 Presentation of Interview Results	285
8.1.1 External influence upon Tool use (Sketching & 3D CAD).....	289
8.1.2 Influence of Tool's Character.....	293
8.1.3 Designer Expertise in Tool use.....	298
8.1.4 Convergence of Design Intentions & Support of Divergent Activity .	302
8.1.5 Support of Detail and Development Design.....	305
8.1.6 Confirmation of Concept (3D CAD) and Inability to Communicate Reality (hand sketch).....	309
8.1.7 Commitment to Design Intent (3D CAD) and Uncommitted Character (hand sketch).....	311
8.1.8 Communication of Design Intent and Facilitator of Collaboration	313
8.1.9 Design Thinking and Reflective Design Activity (hand sketch)	317
8.2 Discussion	319
Chapter Summary	323
Chapter 9: Conclusions	325
9.1 First Research Objective & Research Question 1	325
9.2 Second Research Objective & Research Question 2	326

9.3 Third Research Objective & Research Question 3	329
9.4 Fourth Research Objective & Research Question 4	334
9.5 Reliability of Results	335
9.6 Meeting the Research Aim & Contribution to Knowledge	336
9.7 Future Research.....	338
References	340
Publications	351
Appendix A	352
<i>Surveys of Design Practitioners: Transformations</i>	352
Appendix B	357
<i>Surveys of Design Practitioners: Embodiment</i>	357
Appendix C	362
<i>Surveys of Design Practitioners: Communication</i>	362
Appendix D.....	367
<i>Surveys of Design Students: Part I</i>	367
Appendix E	373
<i>Surveys of Design Students: Part II</i>	373
Appendix F	379
<i>Practitioner Interview Guide</i>	379
Appendix G.....	383
<i>Interview Transcripts with Annotation</i>	383
Appendix H.....	442
<i>IDsite Pilot Survey: Online Questionnaire</i>	442
Appendix I	446
<i>IDsite Validation: Letter of Invitation</i>	446
Appendix J.....	447
<i>IDsite Validation: Online Survey</i>	447
Appendix K.....	451
<i>IDsite Validation: Student focus Group Questionnaire</i>	451

Appendix L	454
<i>IDsite Validation: Survey Methods Results Database</i>	454
Appendix M	458
<i>IDsite Validation: Responses to Open-ended Question</i>	458
Appendix N.....	464
<i>Set of IDsite plates</i>	464
Appendix O.....	475
<i>IDsite</i>	475

List of Figures & Tables

Chapter 1

Figure 1.1 Model of the industrial design process: divergent concept design through to convergent detail design

Figure 1.2 7 Phase Research Methodology

Chapter 2

Figure 2.1 Polished stone Neolithic age axe head

Figure 2.2 Pennsylvania Railroad S-1 locomotive, designed by Raymond Loewy, 1938

Figure 2.3 Sony Walkman, Sony Corporation, 1978

Figure 2.4 The juicy Salif lemon squeezer

Figure 2.5 Bruce Archer's model of NPD showing linear development

Figure 2.6 Ulrich & Eppinger's model of NPD

Figure 2.7 Macro of Ulrich and Eppinger's concept development stage in NPD

Figure 2.8 Cross' simplified model of the design process

Figure 2.9 French's model of NPD

Figure 2.10 Roy's model of the design process

Figure 2.11 Pugh's model of 'Total Design' in NPD

Figure 2.12 Baxter's model of design activity during NPD

Figure 2.13 Cross' eight stages of design process located within a problem/solution model

Figure 2.14 Model of design activity progressing towards convergence with periods of iterative divergence

Figure 2.15 Design Council's 'Double diamond' model of design process

Figure 2.16 Lawson's model of design thinking

Figure 2.17 Model of the industrial design process

Figure 2.18 Refined concept sketches of Motorola headset

Figure 2.19 Initial concept ideas as sketches by Behar

Figure 2.20 Damini's sketch on the back and front of a rail ticket

Figure 2.21 Sketches by Behar used to explore design detail during concept design

Figure 2.22 Initial 'brain-storm' sketches for LabTech digital microphone

Figure 2.23 Case study illustrating use of various tools during development design

Figure 2.24 Propeller's use of sketches and a prototype

Figure 2.25 Simple CAD model for use in proof of concept

Figure 2.26 The development of initial concept sketches to evolve design proposals

Figure 2.27 Shelled CAD model for use in support of engineering

Figure 2.28 Use of CAD in collaboration with engineers and the subsequent prototype

Figure 2.29 Sakai's CAD drawings of engineering detail

Chapter 3

Figure 3.1 Jonson's 'self-completion' method of data gathering

Figure 3.2 Stolterman's et al Tool-in-Use model of design activity

Figure 3.3 Example sketch embodiments often made during concept design practice

Figure 3.4 Conceptual ketch model, foam, card and 'found objects'. Dyson

Figure 3.5 Screen shot from Nugent's idsketching resource site

Figure 3.6 Example CAD model. Created using Rhino software

Figure 3.7 Rapid prototyping offers opportunity for fully functional design embodiment

Figure 3.8 Haptic force-feedback device in use

Figure 3.9 Dorta's hybrid ideation space in use.

Figure 3.10 Wacom Cintiq Graphics tablet in use during design embodiment

Figure 3.11 Engestrom's model of human activity

Figure 3.12 Model of industrial design activity and tool use based on the Engestrom's model

Chapter 4

Figure 4.1 Pei et al's taxonomy of design representations

Figure 4.2 Stolterman's classification of design tools mentioned by subject designers

Figure 4.3 Stolterman's list of design activities mentioned by subject designers

Figure 4.4 Hybrid use of sketching and digital graphics tools

Figure 4.5 Sketches used to communicate intentions towards functionality

Figure 4.6 Taxonomy of 10 design tools within 3 stage model of design process

Figure 4.7 Section of taxonomy showing 3 stages in design practice: concept, development and detail design

Figure 4.8 Subdivision of concept, development and detail design

Figure 4.9 Classification of tools within taxonomy and specific examples of tool types

Figure 4.10 Design embodiments made through the use of tools

Figure 4.11 Classification of concept design tools within the taxonomy

Figure 4.12 Example of hand sketching as design embodiment

Figure 4.13 The kinds of sketches used to support design practice

Figure 4.14 Image taken from graphics tablet using digital sketching software, SketchBook Pro

Figure 4.15 The kinds of digital sketching used to support design practice

Figure 4.16 Velasquez-Posada's classification of conventionally made models

Figure 4.17 Styro-foam concept sketch model

Figure 4.18 The kinds of sketch modelling used to support design practice

Figure 4.19 'Desk-top' 3D Printer

- Figure 4.20 The kinds of 3D printing used to support design practice
- Figure 4.21 Classification of development design tools within the taxonomy
- Figure 4.22 Rendered using Adobe's Photoshop graphics tools
- Figure 4.23 The kinds of digital graphics tools used to support design practice
- Figure 4.24 Conventional graphics tools
- Figure 4.25 The kinds of conventional graphics tools used to support design practice
- Figure 4.26 Design embodiment through 3D CAD
- Figure 4.27 The types of 3D CAD tools used to support design practice
- Figure 4.28 Classification of detail design tools within the taxonomy
- Figure 4.29 2D CAD tools used in the embodiment of engineering drawings
- Figure 4.30 The types of 2D CAD tools used to support design practice
- Figure 4.31 3D System's iPro 9000 SLA rapid prototyping machine
- Figure 4.32 The kinds of RP tools used to support design practice
- Figure 4.33 Traditional model making techniques
- Figure 4.34 The kinds of conventional modelling tools used to support design practice

Chapter 5

- Figure 5.1 UTC: Mode of Communication. Communication to other stake holds and/or communication to oneself through reflection-in-action
- Figure 5.2 Designer engaged in reflection-in-action
- Figure 5.3 The rabbit-duck illusion. An illustration of ambiguity in representation
- Figure 5.4 The design sketch and ambiguity in design embodiment
- Figure 5.5 UTC Transformational Ability. Movement from one idea to a new idea and/or work on variations of the same idea
- Figure 5.6 The vertical transformation of design solution ideas through CAD tools
- Figure 5.7 Goel's modes of transformation as they relate to design embodiment (Symbol systems), design process (Design phases)
- Figure 5.8 Contrasting Level of Detail seen through the use of different design tools
- Figure 5.9 The communication of different Level of Commitment to design intent

Chapter 6

- Figure 6.1 Section of taxonomy showing ten design tools used in the surveys
- Figure 6.2 Prompt card used in survey of graduates to support understanding of terms
- Figure 6.3 Example of revised graduate designers survey page
- Figure 6.4 Page 1 of Interview Guide with illustration of design process
- Figure 6.5 NVivo Node Tree for data coded under 3D CAD
- Figure 6.6 NVivo Node Tree for data coded under hand sketching

Chapter 7

- Figure 7.1 Relationship between mediating design tool and design embodiment
- Figure: 7.2 Hand sketching is useful in the representation of design detail (UTC: Level of Detail)
- Figure: 7.3 Hand sketching is useful in representing artistic/creative form (UTC: Level of Detail)

Figure 7.4 Hand sketching is useful in representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.5 Hand sketching is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.6 Hand sketching is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.7 Hand sketching tool use communicates high levels of commitment (UTC: Level of Commitment)

Figure 7.8 Hand sketching is useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.9 Hand sketching aids reflection & generation of ideas (Mode of Communication)

Figure 7.10 Digital sketching is useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.11 Digital sketching is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.12 Digital sketching aids reflection and the generation of idea (UTC: Mode of Communication)

Figure 7.13 Digital sketching is useful in representing design detail (UTC: Level of Detail)

Figure 7.14 Digital sketching is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.15 Digital sketching communicates a high Level of Commitment (UTC: Level of Commitment)

Figure 7.16 Sketch modelling is useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.17 Sketch modelling is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.18 Sketch modelling aids reflection and the generation of ideas (UTC: Mode of Communication)

Figure 7.19 Sketch modeling is useful in representing design detail (UTC: Level of Detail)

Figure 7.20 Sketch modeling is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.21 Sketch modelling communicates commitment to design intent (UTC: Level of Commitment)

Figure 7.22 Sketch modeling is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.23 3D Printing is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.24 3D Printing aids reflection and the generation of ideas

Figure 7.25 3D Printing is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.26 3D Printing is useful in representing design detail (UTC: Level of Detail)

Figure 7.27 3D Printing is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.28 3D Printing communicates high levels of commitment (UTC: Level of Commitment)

Figure 7.29 3D Printing is useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.30 Digital graphics tools are useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.31 Digital graphics tools are useful for representing design detail (UTC: Level of detail)

Figure 7.32 Digital graphics tools are useful for design work that moves easily between ideas (UTC: Transformation Ability)

Figure 7.33 Digital graphics tools are useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.34 Digital graphics tools are useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.35 Digital graphics tools communicate a high level of commitment (UTC: Level of Commitment)

Figure 7.36 Digital graphics tools are useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.37 Digital graphics tools aid reflection and the generation of ideas (UTC: Mode of Communication)

Figure 7.38 Conventional graphics tools are useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.39 Conventional graphics tools are useful in representing design detail (UTC: Level of Detail)

Figure 7.40 Conventional graphics tools are useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.41 Conventional graphics tools are useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.42 Conventional graphics tools are useful for design work on variations of the same design ideas (UTC: Transformational Ability)

Figure 7.43 Conventional graphics tools communicate a high level of commitment (UTC: Level of Commitment)

Figure 7.44 Conventional graphics tools are useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.45 Conventional graphics tools aid reflection and the generation of ideas (UTC: Mode of Communication)

Figure 7.46 3D CAD is useful for representing artistic & creative form (UTC: Level of Detail)

Figure 7.47 3D CAD is useful for representing design detail (UTC: Level of Detail)

Figure 7.48 3D CAD is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.49 3D CAD is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.50 3D CAD is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.51 3D CAD communicates a high level of commitment (UTC: Level of Commitment)

Figure 7.52 3D CAD is useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.53 3D CAD aids reflection and the generation of ideas (UTC: Mode of Communication)

Figure 7.54 Model Making is useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.55 Model Making is useful for representing design detail (UTC: Level of Detail)

Figure 7.56 Model Making is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.57 Model Making is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.58 Model Making is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.59 Model Making communicates a high level of commitment (UTC: Level of commitment)

Figure 7.60 Model Making is useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.61 Model Making aids reflection and the generation of ideas (UTC: Mode of Communication)

Figure 7.62 Rapid prototyping is useful in representing design detail (UTC: Level of Detail)

Figure 7.63 Rapid prototyping is useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.64 Rapid prototyping is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.65 Rapid prototyping is useful for communicating intentions to others (UTC: Mode of communication)

Figure 7.66 Rapid prototyping is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.67 Rapid prototyping is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.68 Rapid prototyping aids reflection and the generation of ideas (UTC: Mode of Communication)

Figure 7.69 2D CAD is useful for representing design detail (UTC: Level of Detail)

Figure 7.70 2D CAD is useful for representing artistic/creative form (UTC: Level of Detail)

Figure 7.71 2D CAD is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Figure 7.72 2D CAD communicates a high level of commitment (UTC: Level of Commitment)

Figure 7.73 2D CAD is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Figure 7.74 2D CAD is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Figure 7.75 2D CAD is useful for communicating intentions to others (UTC: Mode of Communication)

Figure 7.76 2D CAD aids reflection and the generation of ideas (UTC: Mode of communication)

Figure 7.77 Relationship between mediating design tool and design practitioner

Figure 7.78 Responses to 8 attitude questions on the character of hand sketching tools

Figure 7.79 Hand sketching is useful for representing design ideas in an unambiguous way

Figure 7.80 Responses to 8 attitude questions on the character of digital sketching tools

Figure 7.81 Digital sketching is useful for representing design ideas in an unambiguous way

Figure 7.82 Responses to 8 attitude questions on the character of sketch modelling

Figure 7.83 Sketch modelling is useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.84 Sketch modelling is useful for design work on variations of the same design idea (Vertical Transformations)

Figure 7.85 Sketch modelling aids reflection and the generation of design ideas

Figure 7.86 Sketch modelling is useful for representing design ideas in an unambiguous way

Figure 7.87 Responses to 8 attitude questions on the character of 3D printing tools

Figure 7.88 3D printing is useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.89 3D printing is useful for design work to aid reflection and the generation of design ideas

Figure 7.90 3D printing is useful for design work on variations of the same design idea (Vertical Transformations)

Figure 7.91 Responses to 8 attitude questions on the character of digital graphics tools

Figure 7.92 Digital graphics tools are useful for representing the engineering detail of design ideas

Figure 7.93 Responses to 8 attitude questions on the character of digital graphics tools

Figure 7.94 Conventional graphics tools are useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.95 Conventional graphics tools are useful for design work that aids reflection and the generation of design ideas

Figure 7.96 Conventional graphics tools are useful for representing design ideas in an unambiguous way

Figure 7.97 Responses to 8 attitude questions on the character of 3D CAD

Figure 7.98 3D CAD is useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.99 3D CAD is useful for design work that aids reflection and the generation of design ideas: Do you agree or disagree?

Figure 7.100 3D CAD is useful for design work on variations of the same design idea (Vertical Transformations). Do you agree or disagree?

Figure 7.101 Responses to 8 attitude questions on the character of conventional model making

Figure 7.102 Model making is most useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.103 Model making is useful for design work that aids reflection and the generation of design ideas

Figure 7.104 Model making is useful for design work on variations of one or the same design idea (Vertical Transformations)

Figure 7.105 Responses to 8 attitude questions on the character of RP

Figure 7.106 Rapid prototyping is most useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.107 Question 8: Rapid Prototyping is most useful for design work that aids reflection and the generation of design ideas: Do you agree or disagree?

Figure 7.108 Question 5: Rapid Prototyping is most useful for design work on variations of one or the same design idea (Vertical Transformations)

Figure 7.109 Responses to 8 attitude questions on the character of 2D CAD

Figure 7.110 Relationship between design practitioner and design embodiment

Figure 7.111 The design tools listed are useful for. Representing design ideas in a more constrained, unambiguous way

Figure 7.112 The design tools are most useful for design work that can move easily between design ideas (Lateral Transformations)

Figure 7.113 The design tools are most useful for design work on variations of one or the same design idea (Vertical Transformations)

Figure 7.114 The design tools aid reflection and the dynamic generation and evolution of design ideas

Figure 7.115 Relationship between responses towards reflection-in-action and lateral transformations for practitioners above and students below

Chapter 8

Figure 8.1 8 Topic of Conversation Nodes across 3D CAD

Figure 8.2 10 Topics of Conversation Nodes across hand sketching

Figure 8.3 Role of External Influence upon Tool Use within model of design activity

Figure 8.4 Topic of Conversation: External Influence Upon Tool Use. Only two Themes of Discussion cited for 3D CAD, seven for hand sketching

Figure 8.5 Role of Influence of Tool's Character within model of design activity

Figure 8.6 Topic of Conversation: Influence of Tool's Character. Seven Themes of Discussion cited for 3D CAD, four cited for hand sketching

Figure 8.7 Role of Designer Expertise in Tool Use within model of design activity

Figure 8.8 Topic of Conversation: Designer expertise in Tool Use. Three Themes of Discussion cited for 3D CAD, six for hand sketching

Figure 8.9 Role of Convergence of Design intentions and Support of Divergent Activity within model of activity

Figure 8.10 Topics of Conversation: Convergence of Design Intent & Support of Divergent Activity. Seven Themes of Discussion cited for 3D CAD, six for hand sketching

Figure 8.11 Role of detail and Development Design within model of design activity

Figure 8.12 Topics of Conversation Support of Detail Design & Support of Development Design, two Theme of Discussion cited for 3D CAD, three for hand sketching

Figure 8.13 Role of Confirmation of Concept and Inability to Communicate Reality within model of design activity

Figure 8.14 Topics of Conversation: confirmation of Concept and inability to Communicate reality. Three Themes of discussion cited for 3D CAD and hand sketching.

Figure 8.15 Role of Commitment to design intent and uncommitted Character within design activity

Figure 8.16 Topics of Conversation: Commitment to design Intent (3D CAD) & Uncommitted Character (hand sketching). Two Themes of Discussion cited for both 3D CAD and hand sketching

Figure 8.17 Role of Communication of Design intent and Collaboration within model of design activity

Figure 8.18 Topics of Conversation: Communication of Design Intent & Facilitator of Collaboration. Two Theme of Discussion cited for 3D CAD, six for hand sketching

Figure 8.19 Role of Design Thinking and Reflective Design Activity within model of design activity

Figure 8.20 Topics of Conversation Support of Design Thinking (four cited Themes) & Reflective Design Activity (two cited Themes)

Chapter 9

Figure 9.1 Model showing use of hand sketching, 2D and 3D CAD during design process

Figure 9.2 Model of industrial design activity and tool use including characteristics of design activity

Figure 9.3 Model of Industrial Design Activity and Tool Use including design process

Tables

Table 1 Summary of models of NPD and industrial design process

Table 2 Table showing UTC's, short descriptors and terms of reference at source

Table 3 The design discipline for which you work

Table 4 Number of years experience and level of expertise

Table 5 Sample of design students

Table 6 Attribute question used in online survey of design practitioners

Table 7 8 Likert scale survey questions and universal tool characteristics measured

Table 8 3 smaller surveys and UTC's measured by each and questions asked

Table 9 Graduate survey split into two shorter surveys through division of 10 design tools

Table 10 Attributes of interview sample group

Table 11 9 Questions asked at interview

Table 12 Number of references made to each design tool

Table 13 28 Themes of Discussion Nodes identified within interview data coded under Tool Node 3D CAD

Table 14 42 Theme of Discussion Nodes identified within references to hand sketching

Table 15 Classification of 28 Theme Nodes relating to 3D CAD under 8 Topic of Conversation Nodes

Table 16 Classification of 42 Themes of Discussion Nodes relating to hand sketching under 10 Topic of Conversation Nodes

Table 17 Survey questions showing most difference between sample groups

Table 18 Topics of Conversation, 3D CAD and hand sketching

Table 19 Presentation of interview results

Chapter 1: Introduction

This research aimed to better understand the industrial designer's use of design tools in the embodiment of intent during the design process. These embodiments of intent take many forms: sketches, digital models, conventionally made and rapidly produced prototypes, design and engineering drawings, low-fidelity 'sketch' models and hybrid digital and hand drawn graphic representations. Through investigation of the designer's attitudes towards the use of various design tools in the embodiment of design intent, the research aimed to help develop a more informed understanding of tool use during design practice. Through understanding the motivations and underlying influences on tool use, opportunities exist to develop a more critical insight into the designer's own role in the manipulation of tools in support of the embodiment and communication of design intent.

1.1 Overview: Industrial Design Tools and Design Activity

Industrial designers are futurists, embodying and communicating a vision of the possible or 'yet-to-be' (Nelson & Stolterman 2003 p135). Since industrial design is separated from industrial manufacture, it is concerned with the specification of design intent prior to production (Cross 2007 p115). Designers use a variety of tools and processes to embody design proposals during studio practice. These embodiments are of yet to be realised artifacts but attempt to communicate design intentionality towards solution ideas. It is through the generation of these solution ideas that the industrial designer explores often ill-defined design problems (Cross 2008, Visser 2006, Goldschmidt 1997). During design activity, the industrial designer is solution focused, using the embodiment of design intentions to navigate the design problem, finally arriving at a specific and detailed proposal (Cross, Op cit p21). To augment this process, the designer employs a variety of design tools. These tools of embodiment;

sketching, drawing, modelling and prototyping support the generation and evolution of design ideas from an open, conceptual phase towards the constrained and detailed specification of intent (Baxter 1995, Ulrich & Eppinger 2003, Visser 2006 p115).

Industrial design practice funnels from an open conceptual and often divergent design phase, through development towards the final convergence and specification of design intentions prior to production. However, although practice is concerned with convergence towards a final specification, it will alternate between periods of iterative divergence and convergence as design activity progresses towards the final specification of the design solution. Figure 1.1 illustrates a generic model of the design process based upon divergent/convergent design activity adapted from (adapted from Cross 2008, p194). Supporting exploration of solution ideas and their communication to stakeholders throughout this dynamic process, the designer's physical embodiment of design intentions is critical for the communication and evolution of design proposals in various ways prior to arriving at final specification and manufacture.

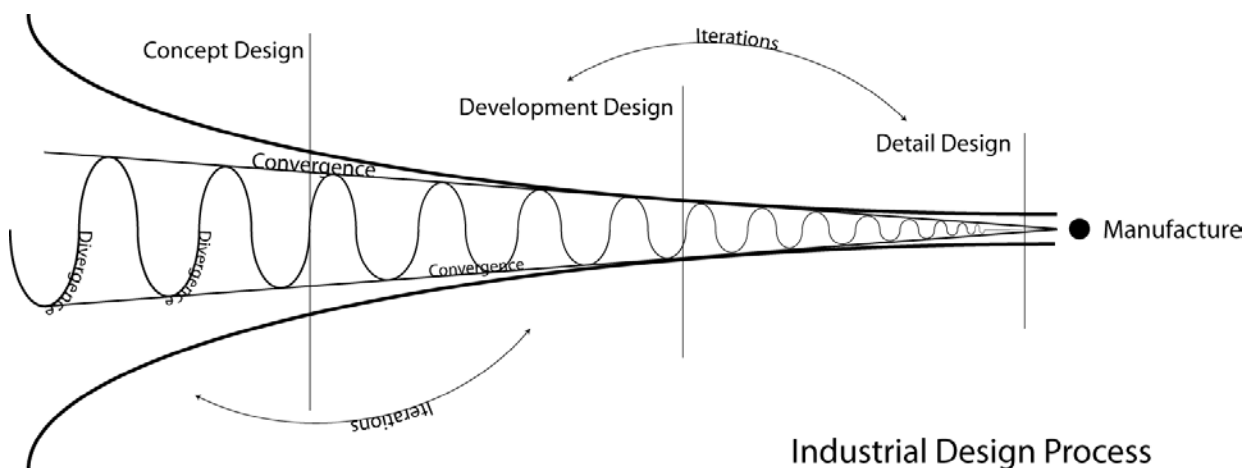


Figure 1.1 Model of the industrial design process: divergent concept design through to convergent detail design

The use of tools of embodiment within design practice, in particular sketching, (Bilda, Demirkan 2003, Fish 2004, Goel 1995, Goldschmidt 1992, Jonson 2005) and also 3D CAD tools (Goel 1995, Dorish 2001, Dorta et al. 2008, Lawson 2004) has received significant interest in design research. Interestingly, there is little empirical work to describe the relationship between the designer's attitudes towards the use of tools and how this may reflect approaches to design practice and tool use. A notable exception is Stolterman's et al (2008 p4) framework for the study of, 'how practicing designers actually view and evaluate tools'. Stolterman (et al 2008) explored design tools in terms

of the purpose of design practice, the activity required to achieve purpose and the tool(s) considered by the designers to best support that activity. Findings indicated the designer's idiosyncratic approach to practice influences tool choice and use (ibid). Baber (2003 p13) refers to the wider context of tool use as allowing, 'their user to act upon their environment, in order to achieve specific goals'. From this perspective tool use is part of a co-dependent activity including the designer, the tool, and the context of design activity (the requirements of design process).

Within contemporary practice, industrial designers use an expanding inventory of design tools (e.g. sketching, 3D CAD, rapid prototyping) to embody design intent (Goel 1995, Pipes 1990, Purcell & Gero 1998). The character of these individual tools, their affordances and constraints, will critically inform industrial design activity.

Digital technology has brought advances in the types of design embodiments made during studio practice. Traditionally, intentions were represented, reflected upon and communicated through analog hand drawing, sketching and craft-based model making tools. With the continuing evolution of emergent digital and hybrid tools, together with those already established, the designer is presented with an increasing variety of media through which design intentions may be embodied. Although this increasing array of tools brings benefits, constraints in the use of 3D CAD software in particular have been identified (Bilda & Demirkan 2003, Goel 1995, Goldschmidt 1992, Dorta et al. 2008, Lawson 2004, Jonson 2002, Robertson & Radcliffe 2009, Tovey & Owen 2000). A literature review suggested a gap in knowledge and understanding of the wider contexts that serve to inform tool use for the embodiment of design intent during industrial design practice; in particular the designer's idiosyncratic approach to practice and tool use and the influence of a dynamic design process as a context of use. This research aimed to address this gap by identifying and exploring how these contexts relate to and critically inform one another. With the increasing availability of various design tools this research is a timely enquiry into the fundamental principles of tool use.

The study presents a more holistic understanding of how designer attitudes, developed through education, working culture and experience of practice, influence tool use. Rather than an investigation of the character of individual tools, the study explores tool use in the context of design as an activity. The influence of the design tool is considered against its idiosyncratic use by the designer: their background and experience as informing the kinds of design embodiments made to support the various requirements of the design process.

1.2 Research Scope and Audience

The study helps develop a more critical understanding and awareness of how design tool use relates to design activity and idiosyncratic approaches to practice. The research provides design educators with a more explicit understanding of tool use in practice which may then be used in design pedagogy. Research findings may also be of use in the development of emergent and established digital design tools to support an understanding of how tool design relates to pragmatic use and the wider contexts of design activity; stakeholder requirements, working methods and conventions. Finally, the study will support designers and related professionals by providing an opportunity to more critically consider tool use within the wider contexts of the design process. And in doing, take a more informed and analytical approach to their own use of tools.

1.3 Research Aim, Objectives & Questions

Research Aim

The research explored the attitudes of industrial designers towards their use of various design tools in the embodiment of intent during design activity. The study aimed to develop a greater understanding of relationships between the character of various design tools, the designer's own idiosyncratic approach to tool use and the often dynamic and complex requirements of a process of industrial design.

The aim of the research, through an investigation of designer attitudes towards their choice and use of tools, was to develop insight into the ways in which the designer's approach to design activity may inform tool use. The research aimed to develop understanding of how the designer's approaches to activity and the use of various tools in the embodiment of design intent, may relate to the designer's awareness of and engagement with the dynamic and complex requirements of a process of industrial design.

Research Objectives

With the aim of developing a greater understanding of the designer's use of tools during design activity, the research has four objectives:

1. To explore the state-of-the-art in terms of current knowledge and understanding of design tool use during industrial design practice with the objective of informing a study of tool use and locating it within an existing body of work.

2. To investigate design tool use during design activity, using existing knowledge to inform the investigation.
3. Through an investigation of design tool use, develop new knowledge related to the designer's use of design tools during design activity.
4. To disseminate new knowledge and understanding of design tool use to design practitioners, design educators and the design research community through conference papers, academic journals and the development of a digital resource (IDsite, Appendix O).

The research aim and four research objectives related to and informed a further four research questions

Research Questions

In order to guide the investigation research question 1 aimed to explore existing work related to the principles and influences that inform tool use during design activity.

1. What are the pre-existing principles, influences and conventions that inform understanding of design tool use in the embodiment of design intent during studio practice?

Literature reviews of the industrial design process and new product development, design tool use in support of design activity, design embodiment, representation and activity theory resulted in a number of secondary research outcomes summarised below:

- The Industrial design process was described as moving through 3 stages of evolution: concept, development and detail design (Chapter 2).
- Activity theory was employed as a framework for exploring design activity and tool use (Chapter 3).
- Design Tools were classified within a taxonomy based upon the 3 stages of the industrial design process (Chapter 4).

- The implicit character of design tools was described through a set of Universal Tool Characteristics (UTCs, Chapter 5).

These outcomes were then applied to the design of survey and interview studies (Chapter 6) to address a second research question:

2. How might knowledge of existing principles be further investigated and what emergent understanding may be gained through this investigation?

Research through survey and interview employed the four outcomes above to explore designer attitudes towards tool use. Findings from the survey (Chapter 7) and interview study (Chapter 8) were used to address a third research question:

3. What might this emergent understanding tell us of the practitioner's attitudes towards and use of design tools during studio practice?

Finally, the dissemination of findings to a practice orientated audience was considered. This resulted in the design and development of a design tool (Appendix O, IDsite):

4. How might research findings be best communicated to practicing designers to foster a more critical engagement with design tools?

1.4 Research Methodology

The research aimed to explore designer attitudes towards tool use and, through this exploration, come to a more holistic understanding of the principles and fundamentals that underpin tool use for the embodiment of design intent at different stages in the design process. The principal research methods used to address these aims were literature review, survey and interview studies. Other research methods were considered (protocol analysis, case study, practice based/lead research) but were rejected in favour of the survey and interview. The study sought to explore the principles and conventions that underpin tool use in practice, observational studies or studies that involved the investigation of activity at a single or few events (protocol was considered insufficient in gathering rich data on the designers' reasons for the use of various tools; their attitudes towards tool use, Chapter 6. This approach is presented in Figure 1.2 as a seven phase research methodology:

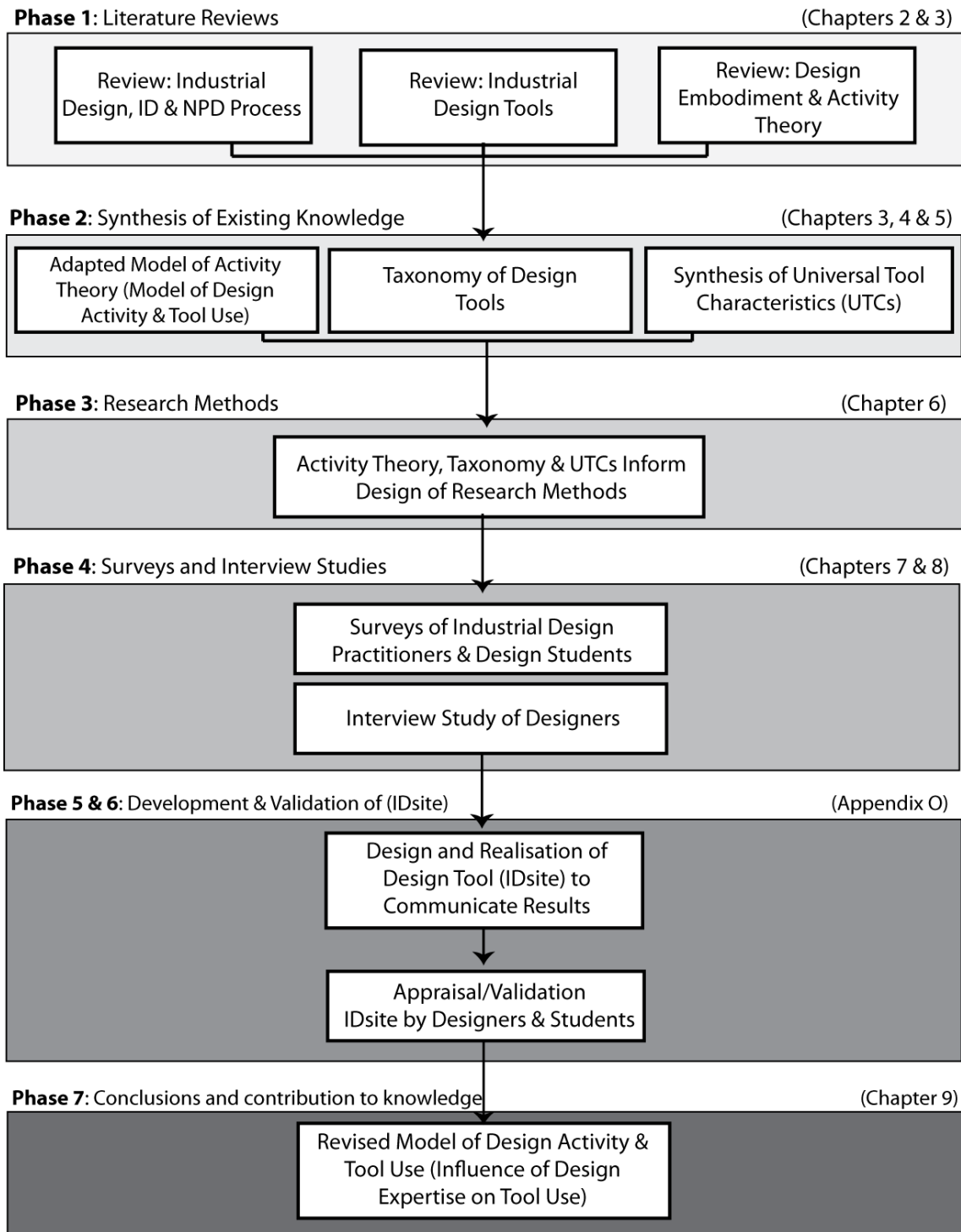


Figure 1.2 7 Phase Research Methodology

1.5 7 Phase Research Methodology and Thesis Structure

The thesis is divided into 9 Chapters. Chapter 1 presents an overview of the research area, its aims and objectives. Research questions are presented followed by a summary of research methodology.

Chapter 2 (Figure 1.2, Phase 1) reviews literature on the definitions of design and design research, the history of industrial design, industrial design practice, design and design embodiment. The industrial design's relationship to both art and engineering is discussed and industrial design located between these two paradigms. Based upon the literature review, a definition of industrial design is presented. A review of the new product development process and industrial design's location within it is also undertaken. Finally, design process is reviewed in greater detail and a 3 stage model of industrial design process presented.

In Chapter 3 (Figure 1.2, Phase 1) design tools are discussed in terms of how their use relates to the pragmatic requirements of the design process, the notion of reflective design activity and the implicit character of design tools. A review of analog, digital and hybrid design tools is then presented. This is followed by a review of activity theory and a discussion of its relevance for the study of design tool use (Figure 1.2, Phase 1). An adapted model of activity theory is presented as a framework for the investigation of design tool use during studio practice (Figure 1.2, Phase 2).

Chapter 4 (Figure 1.2, Phase 2) presents the taxonomy of design tools based upon a 3 stage model of industrial design process. A description of the taxonomy's construction is presented along with justification for the design tools classified within it.

Chapter 5 (Figure 1.2, Phase 2) discusses the identification and synthesis of Universal Tools Characteristics (UTCs) as a means to explore designer attitudes towards the design tools classified within the taxonomy.

In Chapter 6 (Figure 1.2, Phase 3) research methods are described. The use of the adapted model of activity theory (Model of Design Activity and Tool Use), taxonomy of tools and UTCs are used to inform the design of survey and interview studies. Sample groups are described together with survey and interview design. A justification for methods used, their limitations and reliability and the coding systems used in the analysis of research data is presented.

Chapter 7 (Figure 1.2, Phase 4) presents survey results in terms of the adapted model of activity theory (Model of Design Activity and Tool Use, Chapter 3).

Chapter 8 (Figure 1.2, Phase 4) presents research results relating to an interview study of designers. Results are presented and considered against the Model of Design

Activity and Tool Use and survey results. Results are presented and considered against the Model of Design Activity and Tool Use and survey results.

In Appendix O (Figure 1.2, Phase 5) the knowledge and understanding gained through the survey and interview studies is employed in the development of a design tool (IDsite). The design and development of the tool is discussed. Validation of IDsite is presented (Figure 1.2, Phase 6) through a 2 stage validation strategy that saw the site's critique from samples of design practitioners and design students.

Chapter 9 (Figure 1.2, Phase 7) presents conclusions in light of research results. Results are discussed in terms of their ability to address the research aims and answer research questions. This is followed by consideration of the reliability of results, strengths and limitations. The contributions to knowledge in understanding design tool use during industrial design practice are presented and future research directions suggested.

Chapter 2: Design and Industrial Design Practice

Introduction

The Chapter reviews some of the principles that inform understanding of design as a human activity. Industrial design research is described as broadly locate within two paradigms: design process and outcome; and cultural and social contexts. A history of industrial design is presented, describing its emergence from a separation of craft and the industrial revolution, the evolution of industrial design in the United States and Europe through the work of key practitioners such as Loewy and Dreyfus. The influence of technology on industrial design practice is discussed as it continued to evolve through the middle of the 20th century and emergence of academic, government and professional bodies to foster and promote the interests of industrial design such as the COID in Britain and the IDSA in the US. A review of existing definitions of industrial design with particular reference to the embodiment of design intent through drawing, sketching, digital and hybrid tools, model making techniques and prototyping is discussed. Industrial design is described in terms of its relationship to art, creativity and engineering for manufacture.

The Chapter proceeds with reviews of existing models of the New Product Development process and industrial design's role within it. This review leads on to the presentation of a simplified model of industrial design practice which progresses through three stages: concept, development and detail design. These three stages are discussed in terms of the design activity seen in each phase; the design tools used and design embodiments made.

2.1 Design

The word design means different things to different people and is dependent upon the context of its use. Micklethweight (2002), in a doctoral study asking the question, 'What is Design?' mapped the term's many meanings to suggest, 'design means different things to different people and, as such, is heavily dependent upon the context of the word's use' (ibid p298). The difficulty in establishing a universal definition of design is a result of the subjective meaning of the word and its dependency upon idiosyncratic use and context (Lawson 2006). Design may refer to an act or process of designing, the results of the process, the products manufactured with the aid of design, or the look of a product (Julier 2000 p30). As such, existing discourse on a definition of design is, much contested (ibid). Heskett (2002 p3), when considering a definition of design, describes it as, 'full of incongruities, has innumerable manifestations, and lacks boundaries that give clarity and definition'.

Potter (2002 p10), like Micklethweight (Op cit), reminds us of the need to refer to design in a specific context and so avoid any definition of the word becoming, 'hopelessly abstract' (Op cit). However, at the core of design practice is the transformation of existing situations into preferred ones (Elhoff & Marshall 2008 p109). And it is this ability to imagine and suggest intentions towards the what-might-be that is the focus of this research.

2.2 Design as Human Activity

Design is a fundamentally human characteristic. The ability to think ahead and consider alternatives helps define what it is to be human:

One thing that distinguishes us from animals is our capacity to conduct quite conscious and complex mental analysis...We can make plans or designs and carry them out over the long term: we can 'think ahead'.

(Cross 1992 p8)

Figure 2.1 illustrates early human engagement with design as Neolithic humans shaped stone to provide the cutting edge of an axe head as a tool to be used to assist future needs.



Figure 2.1 Polished stone Neolithic age axe head

Cross (ibid) describes design as tied to an ability to think in the abstract and consider what might be. Design can be seen as a universal characteristic possessed by all and that it is this underlying ability that describes an epistemology of ‘designerly ways of knowing’:

There are forms of knowledge peculiar to the awareness and ability of a designer, independent of the different professional domains of design practice.

(Cross 2007 p124)

Design is an ability inherent in all but a distinction can be made between those who earn a living from the practice of design (Potter 2002). Cross (Op cit, p.38) describes these professionals as having, ‘highly developed design abilities’. An important distinction between the professional designer and the idea of a universal ability to design is the professional’s preoccupation with design for other people (Lawson 2006). Although design may be described as an ability inherent to all people, and this is significant for the study of design knowledge (Cross 2007), this study is concerned with those that choose it as a profession, and in particular the industrial design practitioner.

The design professions or disciplines are numerous and have continued to splinter with the emergence of digital culture (Heskett 2002 p7). Industrial design is often classified as a discipline of three dimensional design; design for the production of the three dimensional artefact; product, automotive and furniture design (ibid).

What binds these disciplines together, however, is the visually creative nature of design activity (Cross 2007 p33). Critical to studio practice is the embodiment and

communication of design intentions of the yet-to-be through the use of design tools such as sketching, model making and, more recently, 3D CAD, rapid prototyping and emergent haptic digital technologies. It is the design practitioners use of these tools and their influence upon practice that is the subject of this investigation.

2.3. Design Research

A definition of contemporary design research criteria remains a priority of many academics in the field. In answer to the question, 'Does there exist typical criteria in design research?' Jacobs (In Jones 1998 p5) suggests, 'I doubt if anyone has yet found a definition of designerly research that does not risk excluding or inhibiting imaginative work for the sake of academic respectability.' However, progress has been made, most noticeably by Cross (2007).

Cross (ibid) describes design research as located within three distinct areas: research into people, processes and products. He suggests there are, 'designerly ways of knowing' which are apart from science and the arts. Although research into design must necessarily have academic rigour, research methods may differ from other academic disciplines such as the humanities or sciences. This is because design knowledge has a character apart from that of the scientific tradition or the arts.

The "ways of knowing," the values of science are rationality and objectivity, those of art are reflection and subjectivity, and those of design are imagination and practicality. Similarly, the "ways of finding out," the intellectual skills, can be differentiated: those of science are experiment and analysis, those of art are criticism and evaluation, and those of design are modeling and synthesis.

(Cross 1999 p7)

Existing literature on design and designing may also be broadly divided into two spheres of enquiry. First, work focusing on the influence of design, both process and outcome, upon culture and society (Julier 2000, Heskett 2002, Forty 1986, Raizman 2003). In this context, design is discussed in terms of its political, social and cultural influence, both historically and in contemporary practice, or the resulting designed outcome and its impact/place within society and a material culture. Those interested in the socio-cultural implications suggest design and designing should be studied in terms of relationships between design and the culture within which the designed artefact exists. Julier's (2000), for example, is concerned with the consumption of the designed

object, the impact of social trends upon design; the wider narratives that exist around the interplay between design, mass production and the industrialised society.

A second body of work is concerned with a study of design that focuses on the act of designing rather than the wider significance of the product of design activity, 'Many definitions of design focus on the result of the activity...ignoring the nature of the activity' (Visser 2006 p115). Although these two paradigms must mutually inform one another there appears to be a tension between the two approaches. In his influential book, *Objects of Desire: Design and society since 1750*, Forty's (1986) summation indicates this tension:

Only by exploring this process [design's relationship with society] and by shifting our attention away from the person of the designer can we properly comprehend what design is, and appreciate how important it has been in representing to us the ideas and beliefs through which we assimilate and adjust to the material facts of everyday life.

(Forty 1986 p245)

Although admitting the importance of design as a cultural phenomenon, others consider a more practice-centric study of design is required. An over emphasis on the social context can be at the expense of understanding design practice:

Vulnerable to a tendency to over-emphasize the context by ignoring the individual characteristics and will of designers, and relegating their role to that of deterministic instruments of social, economic or political systems and values.

(Heskett 1980 p105).

This study locates within the body of work, exploring the practice of design and, specifically, the designer's use of tools in the embodiment and communication of design intent.

2.4. Research in Design Practice

The term design, as it is used in the context of practice, refers to the act of designing. This activity is concerned with creating something new or refining something to meet a perceived need, purpose or solve a problem, 'courses of action aimed at changing

existing situations into preferred ones' (Simon 1996 p111). Dependent on the design discipline, the designer may or may not be responsible for the final design outcome (Schon 1983). In some cases the designer is responsible for the outcome, be it a graphic illustration or a bespoke piece of furniture manufacture (Raizman 2003). However, within industrialised society, and the separation of design from manufacture, it is rare for industrial designers to produce the final outcome of their designs (Forty 1986), although this may be starting to change with the use of additive manufacturing technologies (Evans et al 2002).

Pye (2000 p20) describes the separation of design from production as a separation of workmanship of risk from a workmanship of certainty. Before the separation of craft, craftsmen were tasked with the complete design and realisation of the artefact. The 'risk' was in their hands and they were responsible for the success, or otherwise, of the design outcome. After industrialisation, risk and responsibility moved away from the hands of the craftsmen to be placed with those responsible for the specification of design intent prior to manufacture. In a design process where the designer is separated from the designed outcome, risk is re-located to the specification of design intentions prior to production (Cross 2008, Slack 2006, Pye 2000). Specification becomes a defining feature of industrial design practice prior to a process of manufacture that will result in the duplication, by specified means, of the design solution.

Design, as it is used in this study, describes a process which proceeds through a course of action to achieve the aim of final specification of design intent (Cross Op cit). The intention of design activity is the production of something new or to redefine something that already exists. Within this, the research focuses on the embodiment of design intentions used as a vehicle for moving through a design process to arrive at specification prior to production. These intentions towards solution ideas are embodied using different tools, with varying degrees of specificity, for various purpose prior to manufacture (Nelson & Stolterman 2003).

This research concerns itself with the designer's attitudes towards the use of design tools and what this may tell us about design practice. The research aimed to identify relationships between tool use and wider contexts of influence that inform the use of tools during design practice. Thus this research locates within a paradigm of existing work on the practice of industrial design.

2.5 A History of Industrial Design

Industrial design has a relatively short history which can be traced back to its roots in the industrial revolution and the separation of craft (Slack 2006, Lucie-smith 1983, Noblet 1993). However, there is some disagreement as to the timing of the profession's emergence. Some suggest industrial design, as it is known in modernity, emerged in the early 1900's (Ulrich & Eppinger 2003, Slack 2006, Dormer 1993). Others discuss the use of artisan designers as early as the late 1700's as the forbearers of contemporary industrial design practitioner (Forty 1986, Lucie-smith 1983). All agree, however, that industrial design emerged out of radical changes to systems of production.

Prior to industrialisation, craftsmen designed and manufactured artifacts using a production system based on specialist craft skills developed through apprenticeships to masters (Noblet 1993). Responsibility for the design and manufacture of an object lay in the hands of a single individual (*ibid*). This changed during the industrial revolution, where the separation of craft and the mechanisation of production required the specification of design intent prior to a process of production. Responsibility for the artifact's design moved from the craftsmen to artisan designers and modellers. These new practitioners were responsible for defining the object's form and providing instructions to be followed during manufacture (Cross 2007, Forty 1986). The result was the mass-production of objects that saw the designer, unlike the craftsmen that came before, divorced from a process of production (Lucie-smith 1983). Nineteenth century Britain saw the industrial revolution take hold, and increasingly complex processes of production added new weight and responsibility to the designer's role.

Reaction against these new systems was manifested in the emergence of the arts and crafts movement. Criticism was leveled at a system required to manufacture the mass produced based on nostalgia for the hand made. The artist designers William Morris and John Ruskin were both prominent in this movement, drawing sympathy for their views from a Victorian Britain (Noblet 1993). However, industrialisation continued unchecked, revolutionising systems of manufacture, materiality and society.

By the 1920's a new generation of industrial designers had emerged in the United States. A number of these would go on to gain considerable status (Dormer 1993 p18). Foremost among them were Raymond Loewy and Henry Dreyfus (Heskett 1980 p107-

110, Dormer 1993 p18). Their background of art and illustration contrasted with their European peers, who came to design from engineering or architectural fields (Ullmer & Ishii 2001). European design would also be influenced by the Bauhaus school (1919-1933), with its dictum of form follows function that, 'introduced design as the application of technology and art in equal measure' (Slack 2006 p10). The European perspective was seen in contrast to Loewy's artistic methods that took a more style-centric approach to industrial design. An example of this may be seen in Loewy's restyling of the streamlined S-1 steam locomotive in 1938 (Dormer 1993 p12, Figure 2.2).



Figure 2.2 Pennsylvania Railroad S-1 locomotive, designed by Raymond Loewy, 1938

By the 1960s and 70s others, such as the Japanese and later the Koreans, driven by the quickening pace of technological advance, were producing products for an emerging electronic age. 1978 saw the introduction of the Sony Walkman (Dormer 1993 p42, Figure 2.3), a mix of technological advance and design innovation. By this time increasing competition and a crowded market place further redefined the role of the industrial designer, who had not only to think in terms of function and style, but also consider how to identify and distinguish a product from those around it (Tovey 1997).



Figure 2.3 Sony Walkman, Sony Corporation, 1978

At the start of the 21st century industrial design is practiced by professionals in small design consultants and in-house design offices as part of larger corporations (Ulrich & Eppinger 2003). Professional bodies such as the Industrial Design Society of America¹ and the Design Council in Britain continue to provide a forum for promoting the interests of a community of practitioners. Research into design practice is maturing with industrial design a core interest in groups use as the Design research Society² and the International Association of Societies of Design Research³.

2.6 Industrial Design Practice

The Industrial Design Society of America (IDSA) provides the following definition of the role and responsibilities of the industrial designer:

¹ 'The Industrial Designers Society of America (IDSA) is the world's oldest, largest, member-driven society for product design, industrial design, interaction design, human factors, ergonomics, design research, design management, universal design and related design fields' (IDSA 2011).

² 'The Design Research Society is the multi-disciplinary learned society for the design research community worldwide.' (Design Research Society 2011).

³ 'The purpose of the Association is to promote research or study into or about the activity of design in all its many fields of application, through encouraging collaboration on an international level between independent societies of design research' (Op cit).

Industrial design (ID) is 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 2010)

Industrial design is part of a paradigm of three dimensional design activities that ranges from studio pottery to engineering design (Potter 2002 p11). What binds this diverse range of design activities together is a need to explore and communicate design intent prior to manufacture. In arriving at design specification, the designer will engage in a dynamic process, moving between divergent concept design and convergent detail to finally arrive at specification prior to production.

A defining characteristic of industrial design is its separation from the process of production, 'the designer therefore stands aside from the physicality of the manufacturing process' (Lucie-smith 1983 p7). As a result of this separation the generation of design concepts, and the specification of design intent are the responsibility of the industrial designer (Cross 2007, Visser 2006). At first, as in Joshua Wedgwood's ceramics factory, artisans were employed to draw and model design intent prior to production (Forty 1986). However, as mechanisation took hold in the first quarter of the twentieth century, design specialists with knowledge of the new systems of production emerged. In an increasingly competitive environment, industrial design was valued for its ability to add 'desirability' through form and style (Tovey 1997). These new systems of design for manufacture would have a profound influence on material culture within industrialised society (Dant 1999, Slack 2006).

The literature often discusses the role of Industrial design in terms of the designed artifact's socio-cultural influence and the historical importance of a system of design for manufacture upon society (Forty 1986, Lucie-smith 1983, Conran 1996). Heskett (2002 p9) describes part of the industrial designer's role as being sensitive towards, 'prevailing social and aesthetic concepts'. Lucie-Smith (Lucie-smith 1983 p10) recognises the subjective nature of the designed artifact and its understanding through socially informed perceptions: 'Industrial designer has to deal with the way in which things are perceived, as well as the way in which they objectively exist'. Conran (1996 p22) indicates the multifaceted nature of industrial design practice whilst suggesting that, above all, design is concerned with desirability: 'the first thing I look for, in any

design...is the excitement that comes when something touches a chord, reawakens the memory, or pleases the eye'.

Industrial design practice, more so than engineering design, is concerned with the form and aesthetic of the manufactured artifact (Heskett 1980 p9). A key requirement of industrial design is to give form to an object, its structure and appearance (Schon 1983). However, Industrial design must also be sensitive to materials of production, processes of manufacture (Press & Cooper 2003), and the context of the artifacts use. Within this context it is concerned with aesthetic, form and product identity, in contrast with the industrial engineer, whose interest biases the system of manufacture and product architecture in response to that system (Pei et al 2008).

A further defining feature of Industrial design practice is its solution-focused, goal orientated approach (Visser 2006, Press & Cooper 2003). Design problems are often ill defined and require an open approach which considers multiple solution ideas (Cross, Christiaans et al. 1996). The designer's role in this is to suggest new insights and alternatives solutions. Potter (2002 p17) describes designers as highly problem conscious, where the designer must acquire the ability to synthesise and order information and to suggest creative solutions to ill-defined problems.

It is because of the ill defined nature of the problem and the resulting search for solution ideas, that the embodiment of intentionality through drawings, models and other design tools is a critical part of what it is to engage in industrial design activity. Design tools are used as vehicles, through which, the designer may explore the design problem; identify solution ideas and eventually arrive at the specification of design intent prior to manufacture (Visser 2006 p116, Goel 1995 p91).

2.7. Industrial Design as Embodiment of Intentions

In a pre-industrialised, craft-based society, there is no act of design embodiment; no design representation prior to a process of manufacture (Cross 2008 p3). The artifact being worked upon is the final outcome. In an industrialised society, this process of making comes after a process of design (ibid). Design aims to describe design intentionality towards the finished artifact, 'the most essential design activity, therefore, is the production of a final description of the artifact' (Cross Op cit).

In order to reach a final description of intent, the designer must externalise and evolve design solutions through the embodiment of ideas using a variety of design tools. Lawson (Lawson 2004, p33) describes the designer's use of design embodiment as both a way to communicate intention to others and an aid to the designer's own understanding of the ill defined design problem, 'designers almost always draw, often paint and frequently construct models and prototypes'.

The kinds of tools and processes used in the embodiment of intentions will depend on the stage of the design process the designer is engaged in. Sketches and sketch models are often used during conceptual design and development (Cross 2007 p108). Later, to aid specification, prototypes and CAD engineering software is employed (ibid). Potter (2002 p16) describes design embodiments as instructions for manufacture that may take many forms, 'detailed working drawings, presentation drawings for clients, scale models' (ibid). Common in the use of all tools, however, is the designer's wish to experiment, test and evaluate design intentions (Cross, op cit, Cross 2008 p10). Design practice is a complex mix of influences; from technical and manufacturing constraints to client needs and the designer's own idiosyncratic working methods; their experience and working environment (Cross 2007 p46).

Design embodiment is undertaken to both communicate intentionality to stakeholders and as a way for the designer to evolve their own design ideas (Schon 1983). Ullmer (2001) discusses the industrial designer's role in communication of intentions to facilitate design development in a collaborative process. The designer's communication of intent, through embodiment using different tools, is critical as decisions made by others will influence the designed outcome (Potter 2002). Of the many tools available to the designer, hand sketching remains critical, both for communication with others and in support of self-reflective design activity (Schon Op cit):

From the conceptual thinking behind an innovative new product to the resolution of a difficult moulding problem, the designer will invariably find that, of all these skills, the most important is drawing...drawing is the basic tool of the industrial designer's trade. Without this skill, too many designers are forced to design only what they can draw, rather than what they can design.

(Powell 1985 p6)

Even with the emergence of an increasing variety of digital design tools: 3D CAD, rapid prototyping, 3D printing, graphics tablet, and more recently, haptic technologies (Evans, Wallace et al. 2005), sketching is still valued as a core competency (Pipes 2007 p12). Powell (Op cit) described the ability of sketching to support the designer's thought process as having, 'a conversation with themselves', using design embodiment through sketching to, 'keep pace with the speed of your own thinking' (ibid p6).

Schon (1983 p79) refers to the designer's relationship with embodiment as 'talk back' and 'back-talk'. The complexity of design activities, with its competing influences and responsibilities requires, through embodiment, the designer to test and alter design intentions: 'he shapes the situation in accordance with his initial appreciation of it, the situation "talks back," and he responds to the situation's back-talk' (ibid).

The role of design embodiment is central to the study of design as a process of constructing design representations (Visser's 2006 p115). Design practice moves, via the embodiment of intentions, through the generation, transformation and evaluation of design embodiments to arrive at final specification. Visser (Op cit p153) describes the form and character of the final specification of design intent:

They are so precise, concrete, and detailed that the resulting representations specify explicitly and completely the implementation of the artifact product. This construction is iterative. The difference between the final and the intermediate artifacts (representations) is a question of degree of specification, completeness and abstraction.

(Visser Op cit p153)

With the continued emergence of a variety of digital tools, research aimed at understanding the use of design tools is timely. Although technology continues to have a significant impact, the fundamental requirement of design embodiment informed the earliest definitions of industrial design. Gaspard Monge (In Conran 1996) in 1779 described the aim of design prior to manufacture as a requirement to represent in exacting detail and in two-dimensions, objects of three dimensions. As a result of a requirement to embody design intent, parallels are often drawn between industrial design and the creative arts.

2.8. Art, Creativity and Industrial Design

The first industrial designers were artists and skilled artisans employed for their ability to understand society's changing tastes and fashions and to use this understanding in the artifact's design. As early as the 18th century Josiah Wedgwood's pottery manufacture facilitated the need for trained artisans such as John Flaxman⁴ who were, 'sensitive to the tastes and styles of the day' (Forty 1986 p34). Like the artist, the designer uses semantics to communicate feeling and engender a reaction (Dormer 1993 p11). This commonality can be seen in the work of Italian product designer Philippe Starck, 'Juicy Salif by very dint of its poor utilitarian performance forces one to stand back from it and think about it as an aesthetic object' (Julier 2000 p69, Figure 2.4). Italian design has a stronger tradition of design-as-art tied to the influence of the Avant Garde movement (Dormer 1993). The mass produced becomes an object of display, less concerned with function or practicality than with projecting meaning:



Figure 2.4 Starck's Juicy Salif lemon squeezer

⁴ John Flaxton was one such artisan employed by Wedgwood to model ceramic earthenware to be manufactured during a process that would see, for the first time, the division of labour. This division facilitated the need to standardise designs and to employ individuals whose job it was to creatively produce drawings and models from which the pots would be produced.

Although industrial design may be described as having an artistic component, it is not art (Potter 2002 p20). Industrial design is constrained by other influencing factors: manufacture, materials and user requirements. During industrial design practice the designer's concern is with the communication of intentionality towards the what-might-be. The artist's interest is in the artefact itself. A sculptor or painter will invariably work on a singular artwork, whereas the industrial designer is concerned with the specification of intent, through design embodiment, that is then used in the manufacture of the artefact (Visser 2006 p17). Potter (Op cit) describes creativity, aesthetic and sensory latitude as defining design activity. However, even during conceptual design, where the designer is engaged in a less constrained more creative activity there exist boundaries within which the designer must work.

These boundaries differ from those that define the work of the artist. Industrial design, like art, is sensitive to semantic aesthetic and cultural understanding, but it does not, 'spring from the fountain head of art' (Potter 2002 p21). Industrial design has as much in common with industrial engineering. The outcome of industrial design is the specification of intentions for manufacture (Cross 2008 p4). At each stage of design development the requirements of engineering and manufacture must be considered and satisfied.

2.9. Engineering and Industrial Design

Both industrial and engineering design are concerned with manufacturing products, (Tovey 1997), although this seems to be at odds with the art school tradition of placing industrial design, along with other three dimensional design disciplines such as furniture and ceramics, within schools of art and design. Jones (1981 p4) points to the similarity between industrial engineering design and industrial design by suggesting both industrial and engineering designers are concerned with designing pieces of technology to, 'initiate change in manmade things'.

However, there is much that separates industrial design from engineering design. An engineering designer's responsibility errs towards product architecture and assembly. Industrial designers are more concerned with the appearance and identity of a product (Tovey 1997), how the product communicates and the user's interactions with the designed artefact (Ulrich & Eppinger 2003). Dormer (1993 p9) discusses the industrial designer's role in defining product semantics, 'the meaning of the product, its ability to communicate function'. The engineering designer is precise and systematic, wishing to

test and validate (Lawson 2006, Dormer 1993). The industrial designer works with less understanding of the nature of the end product and so must remain open to the generation of other possibilities (Lawson, *ibid*). Tovey (*Op cit*, p.9) clarifies the role of the industrial designer as distinct from the engineer when suggesting 'the industrial designer has two particular and related functions: to visualize the product concept and to represent alternative design solutions'. In short, the industrial engineer is responsible for the pragmatic manufacture of the designed artefact and the success of the production process. The industrial designer, while required to understand processes of manufacture, is responsible for the generation of solution proposals, and at the same time, consider such principles as product semantics and user interaction.

Tovey (*Op cit*) speaks of the industrial designer's contribution in terms of 'desirability' and 'added value'. Engineers may err towards concern for the artefacts quality and reliability (Tovey *Op cit*, p.9). The latitude between art and engineering, and where design locates between these two, is described by Potter (2002):

The more aesthetic and sensory latitude available within a particular range of design opportunities, the closer they resemble those offered by the practice of 'fine-art'. Conceptual design practice, broadly, may be described as closer to offering aesthetic/sensory latitude. Detail and design for engineering are, 'fields in which the scope of aesthetic 'choice' is truly marginal.

(*ibid* p15)

2.10 A Working Definition of Industrial Design

The Industrial Design Society of America's definition of industrial design indicates the designer's responsibility to provide recommendations of design intent that specify design prior to industrial production:

Industrial designers develop these concepts and specifications through collection, analysis and synthesis of data guided by the special requirements of the client or manufacturer. They are trained to prepare clear and concise recommendations through drawings, models and verbal descriptions.

(IDSA 2010)

Industrial design practice is characterised by a tension between responsibility for the giving of form and semantic desirability, value and usability, and a need to consider engineering and processes of production. Critical in this is the use of design tools in the embodiment of design intent to support communication and the evolution of design proposals. To reflect these competing influences the study uses the following as a working definition of industrial design:

Industrial design practice is concerned with the definition of form, aesthetic and semantic appeal sensitive to the context of the artefact's use. Industrial design activity is separate from manufacture but is constrained by the process of the artefact's final production. The aim of the design process is to evolve design towards final specification prior to engineering for manufacture. In order to test, communicate and evolve design solution ideas, the industrial designer will embody, through various tools, design intentions prior to the manufacturing process.

Before considering the role of design tools in support of design practice (Chapter 3), the following section reviews industrial design in terms of its place within and influence on New Product Development (NPD).

2.11. NPD and Industrial Design

NPD is a staged process concerned with product planning including corporate strategy, market objectives and design (Ulrich & Eppinger 2003). In the following section existing models of the NPD process, indicating the industrial designer's responsibilities within it, are presented to contextualise industrial design practice within the wider context of NPD.

2.11.1 Staged Models of NPD

A definition of NPD evolved from attempts to classify it as a linear model, with each stage building on the previous (Design Council 2007). Bruce Archer (1965) describes the design process as existing within a prescriptive model of NPD. Archer's (ibid) model presents six types of activity undertaken during the NPD process (Figure 2.5). The model is concerned with establishing critical issues (design problem), proposing a course of action (solution explorations) and collecting data to support actions. This is followed by preparation of design proposals (creative phase) and their development

based on the outcome of the analytical phase. Finally, specification for manufacture takes place at the executive phase (specification of design intent):

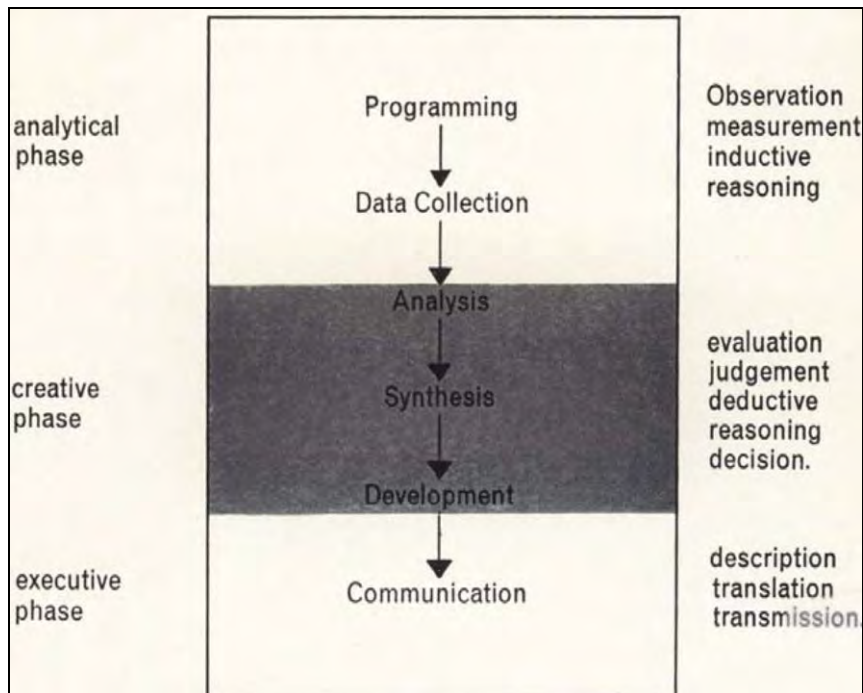


Figure 2.5 Bruce Archer's model of NPD showing linear development published in 1963

Unlike Archer (Op cit) Ulrich's and Eppinger's model (Ulrich & Eppinger 2003 p14) is descriptive rather than prescriptive. A six phase approach to NPD runs from phase 0, 'planning' to phase 5, 'production ramp-up' (Figure 2.6).

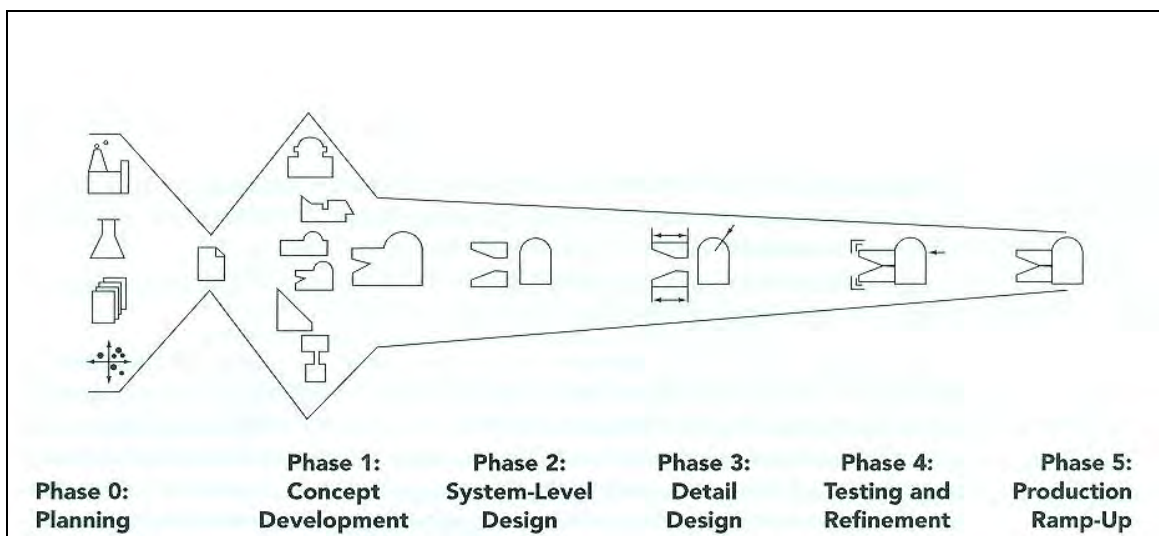


Figure 2.6 Ulrich & Eppinger's model of NPD

Ulrich's and Eppinger's model (Op cit) describes the roles and responsibilities of three groups within the NPD process: marketing, design and manufacturing. The model outlines the responsibilities these groups have in relation to the phase in development. They suggest the industrial designer's key areas of influence locate at the front end of NPD during Phase 1, 'Concept Development' and Phase 2, 'Systems-Level Development'. During Concept Development they refer to the responsibility of industrial design to, 'investigate feasibility of product concepts; develop industrial design concepts, build and test experimental models and prototypes' (Op cit p14). During the Systems-Level Phase the designer, 'generate alternative product architectures, define major subsystems and interfaces' (Op cit p14).

Ulrich and Eppinger also see concept development or the front-end of the NPD process as most challenging due to its complexity, 'demands perhaps more coordination among functions than any other' (Ulrich & Eppinger 2003 p98).

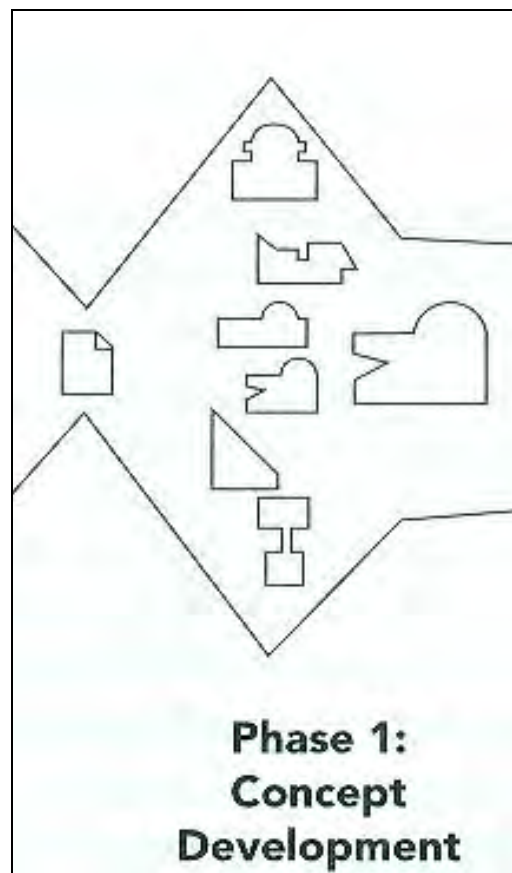


Figure 2.7 Macro of Ulrich and Eppinger's concept development stage in NPD

Ulrich and Eppinger's model progresses from the initial 'clarification of the problem', and the breaking down of the problem into sub-problems. A 'search' for existing solution then takes place, 'search external', through the use of personal and team knowledge to generate concept solution ideas, 'explore systematically' the many concept ideas collected during the search phase and finally involves, 'reflection on the solution(s) generated' (Ulrich & Eppinger 2003 p13-15). Although the model provides a systematic approach to concept development, like other prescriptive models (Archer 1965, Pugh 1990) it has been criticised for its problem-focused approach. Concept development often deals with ill-defined problems (Cross 2008 p11), and to deal with these, 'wicked problems', designers also adopt a solution focused approach to design practice. Through concept generation (solutions), the problem is better defined.

2.12.1. Staged Models of NPD with Iteration

Cross describes a 4 stage model employing a feedback loop to indicate iteration between the generation of solution ideas and their evaluation. Through this generation of solution-focused concepts, new insights emerge and design loops back to generate more satisfactory concepts in light of this new insight (Figure 2.8):

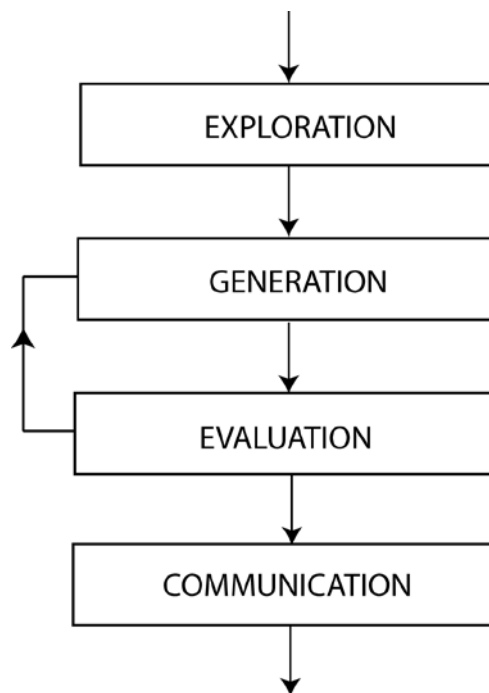


Figure 2.8 Cross' simplified model of the design process

The inclusion of steps leading from one stage to the next, but with feed-back loops suggesting iteration, is also seen in French's (Cross 2008 p31) model of the design process (Figure 2.9):

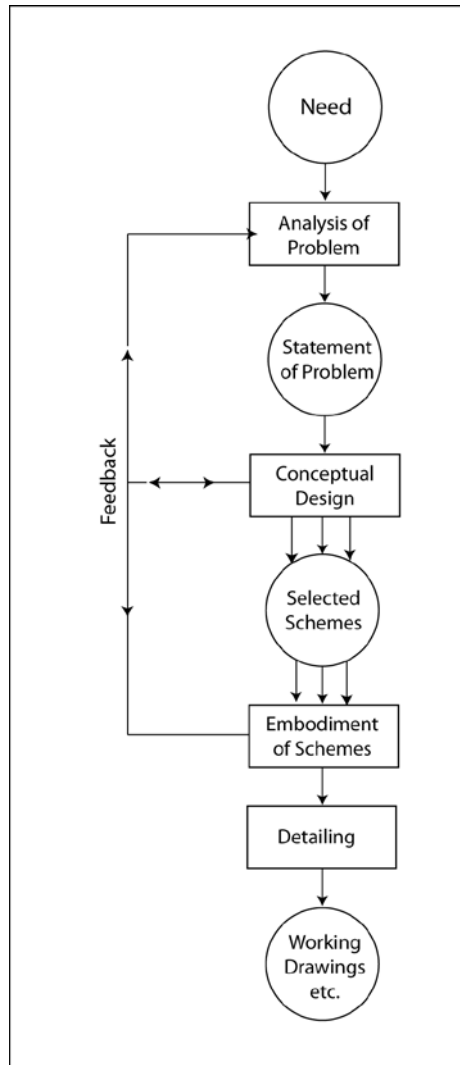


Figure 2.9 French's model of NPD

The circles represent output, the rectangles activities. The model indicates four stages of progression. The first stage being the analysis of the problem resulting in, 'a statement of the design problem...Limitations placed upon the solutions' (French in Cross 2008 p31). At stage two, conceptual design, 'takes the statements of the problem and generates broad solutions'. Embodiment of schemes describes the working-up of concepts in greater detail and the final choice between them. Finally, detailing describes the specification of all parts prior to manufacture (ibid).

A further model of the NPD process is presented by Roy et al (in Press & Cooper 2003 p43). Like Ulrich and Eppinger (2003), Roy's model describes three factors as influencing new product development, manufacturing and engineering, research and design and development (Figure 2.10):

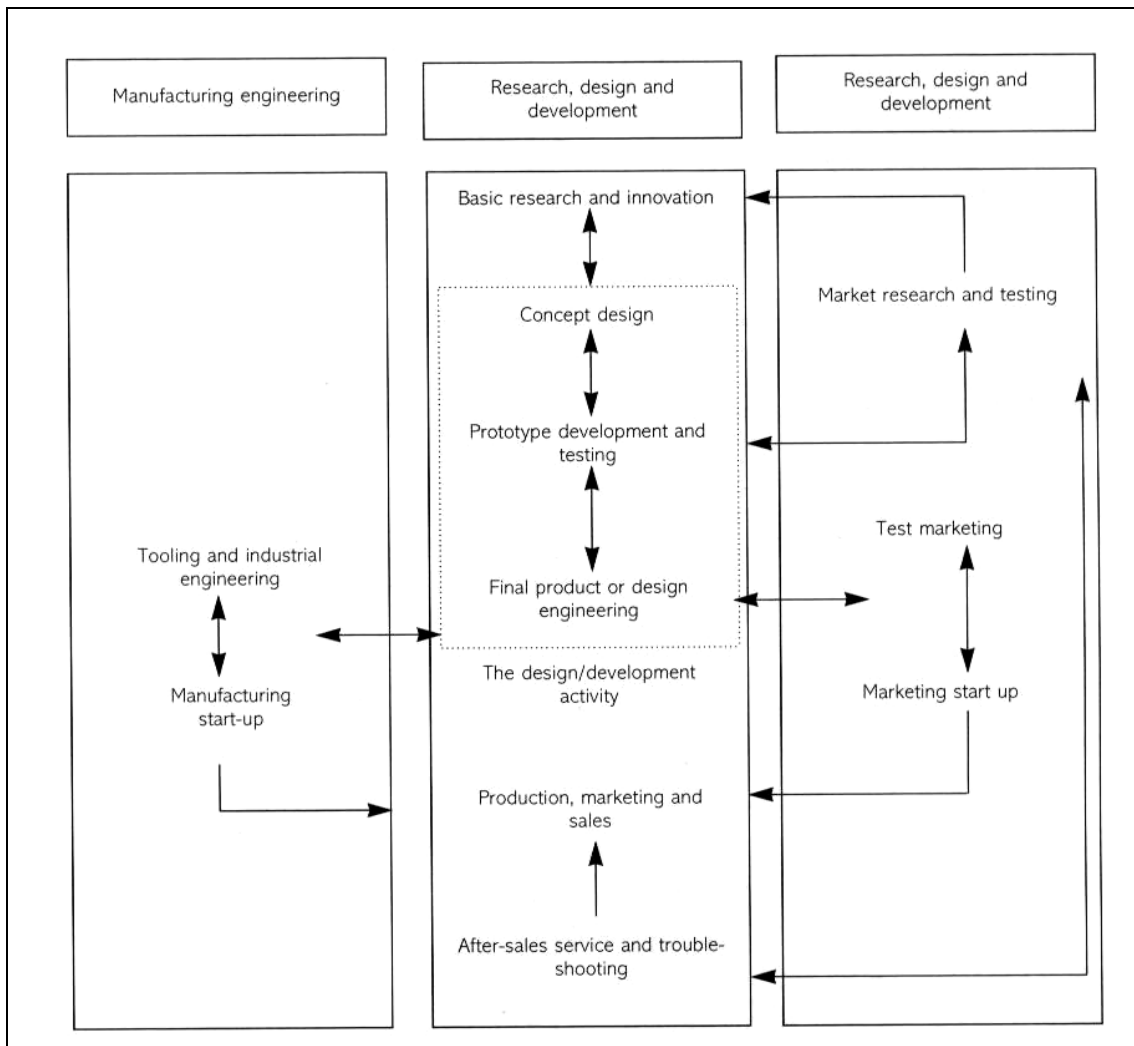


Figure 2.10 Roy's model of the design process

Roy et al (Op cit) suggests that the industrial designer's responsibility is weighted towards concept design and, to a lesser extent, prototype development (centre column, Figure 2.10). The double headed arrows between these phases indicate the iterative nature of practice. This iteration is also seen in Pugh's (1990 p9) six stage approach (Figure 2.11). First marketing, analysis and design specification (where the input from the designer increases) is presented. Next, concept design (the primary influence of the industrial designer), detail design (the remit of engineering designers, manufacture) and finally, sell. Pugh (Op cit) considers the, 'designer's involvement decreases' as the process moves through these stages. The front end, concept designs, he sees as, 'the designer's principle task':

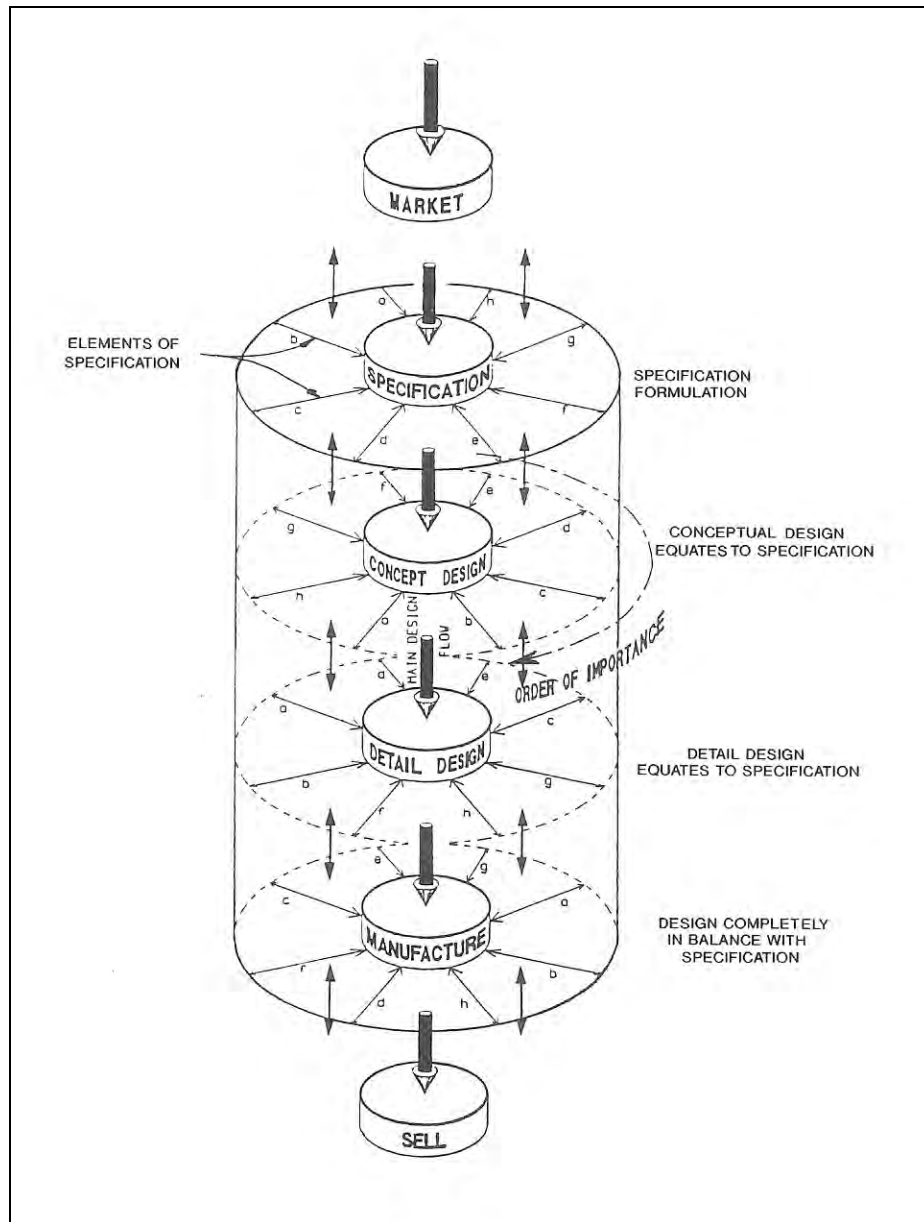


Figure 2.11 Pugh's model of 'Total Design' in NPD

Pugh (1989) emphasises the iterative nature of the model:

At all stages, the design core activity is operated *iteratively*...the main design flow can, and does, often reverse at any point in the design activity'

(Pugh 1990 p6)

Pugh, like Ulrich and Eppinger (Op cit p73), considers the importance of the concept design phase. The expected outcome of this phase are described as complete concept(s) engineered to an acceptable level to establish their validity, unlike Ulrich

and Eppinger (Op cit) and Walker (Op cit), who divide an initial design phase in two. Pugh, on the other hand, describes the concept stage as resulting in more specific solution proposals.

Baxter (1995) presents a six stage approach to NPD (Figure 2.12):

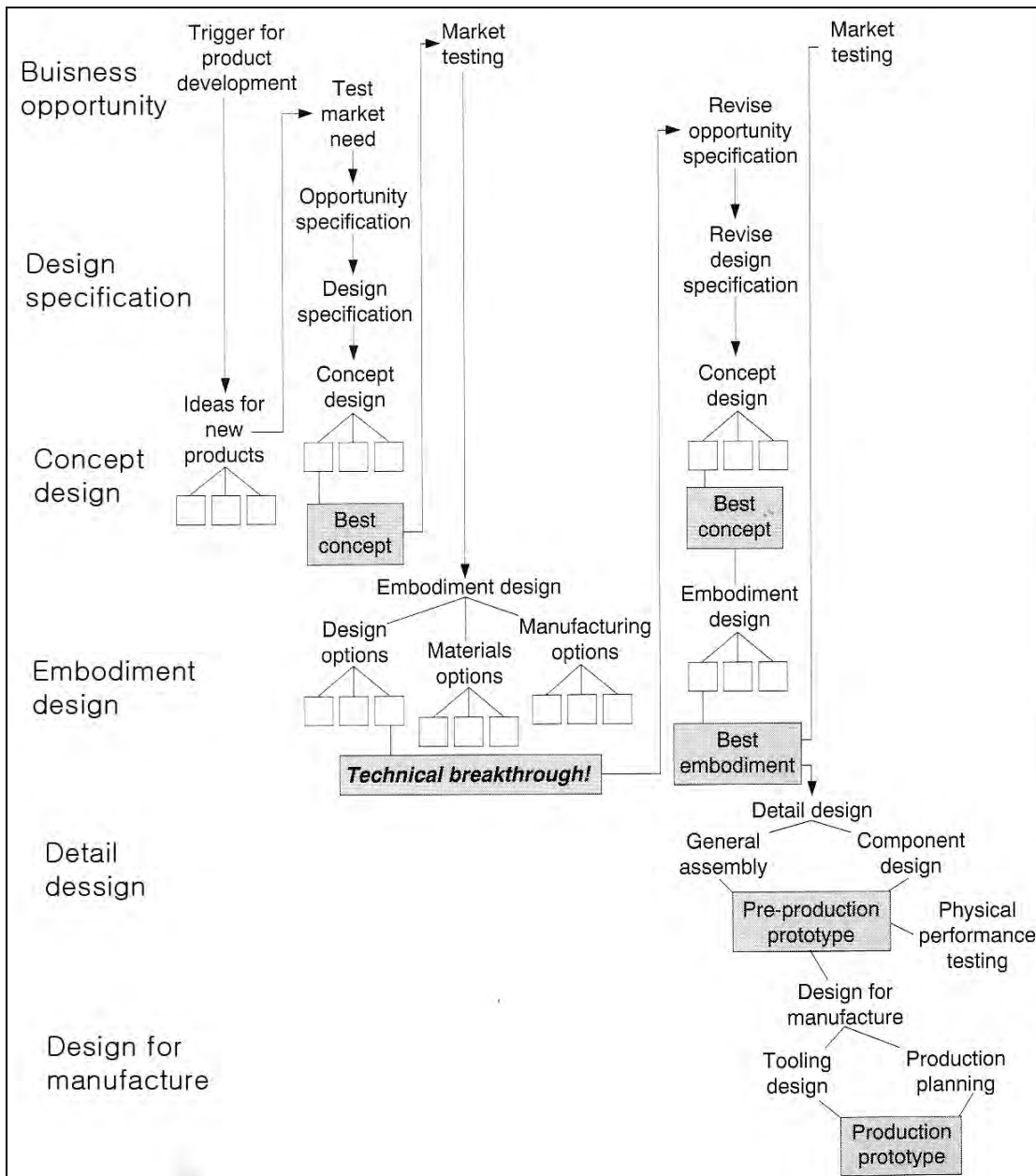


Figure 2.12 Baxter's model of design activity during NPD

The model illustrates three stages of design activity coming after the specification of the design problem. These are termed concept, embodiment and detail design and

come prior to design for manufacture. Instead of interactions represented as feedback loops, arrows flow through the process. Baxter's model (Op cit) indicates the looping-back of ideas through repetition using the terms, 'best concept' and 'revised', suggesting revision of problem specification in light of new insights (Figure 2.12). Baxter (Op cit), like others (Ulrich & Expunger 2003, Press & Cooper 2003, Pugh 1990) describes the industrial design's influence as prevalent during concept and development design; receding during detail design and engineering.

2.12.2 Integrated Models of NPD

Cross (2008 p42) expresses a concern for staged approaches to represent the ill-defined nature of the design problem and the designer's exploration of solution ideas. Cross (ibid) maintains that, 'the designer explores and develops problem and solution together'. His model attempts to capture this co-evolution (Figure 2.13), describing the model as integrating the solution focused activity of design and its use to help the designer understand the ill-defined problem, 'understanding of the problem and of the solution develops together, or co-evolves.' (Cross 2008 p42, Figure 2.13):

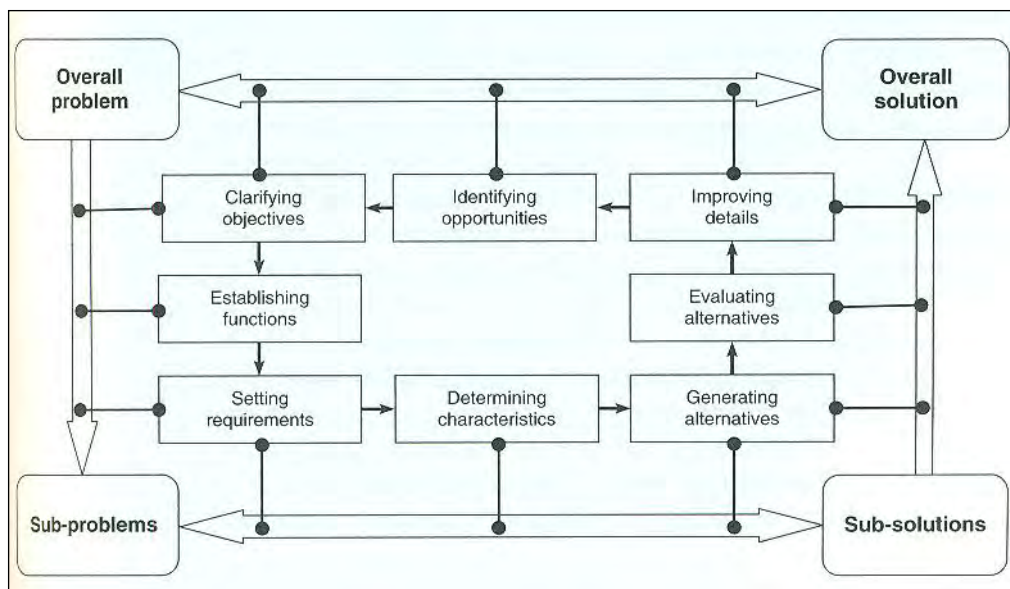


Figure 2.13 Cross' eight stages of design process located within a problem/solution model

Cross' (ibid) model indicates a constant evolution of the problem; the 'problem space' (Figure 2.13, left) and the search for solutions; the 'solution space' (Figure 2.13, Right). Cross emphasises the role of iteration, with the designer moving between problem and solution, sub-problem and sub-solution. This suggests a pattern of progress in design practice, from an open conceptual process, towards a more constrained detailing of design intention, seen in the anticlockwise direction of movement (Figure 2.13).

Positioned within the model, eight procedures within the design process are presented (rectangular boxes, Figure 2.13). The model attempts to describe the structural aspects of design practice; the problem/solution relationship and methods used in support of the evolution of design solutions. Cross' model indicates the fundamental requirement of design to progress solution ideas towards more complete specification of design intent prior to manufacture (Cross 2007 p101, Visser 2006 p115), describing this requirement as 'convergence' (Cross 2008 p194, Figure 2.14):

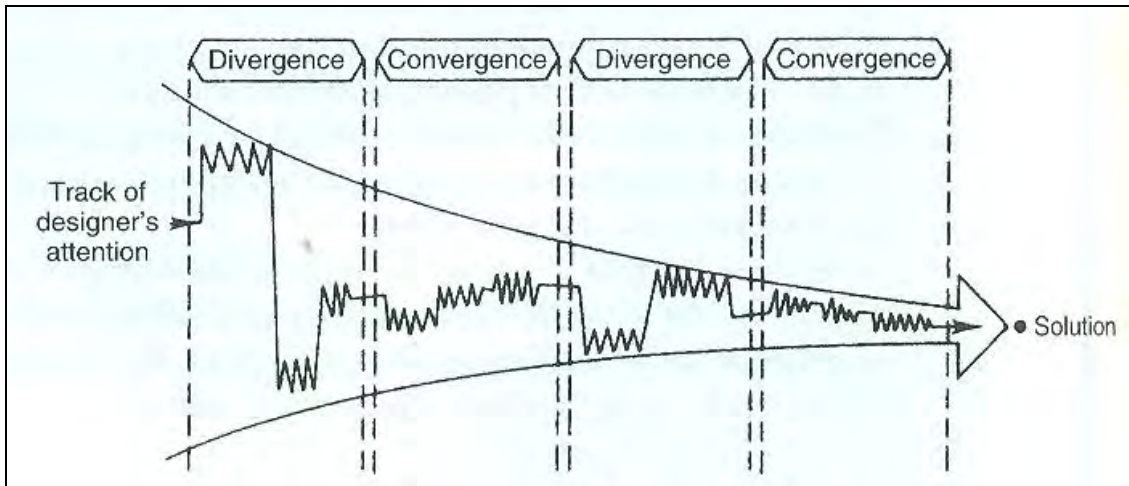


Figure 2.14 Model of design activity progressing towards convergence with periods of iterative divergence

A model of design process published by the Design Council (2010) reinforces the iterative nature of design practice (Figure 2.15):

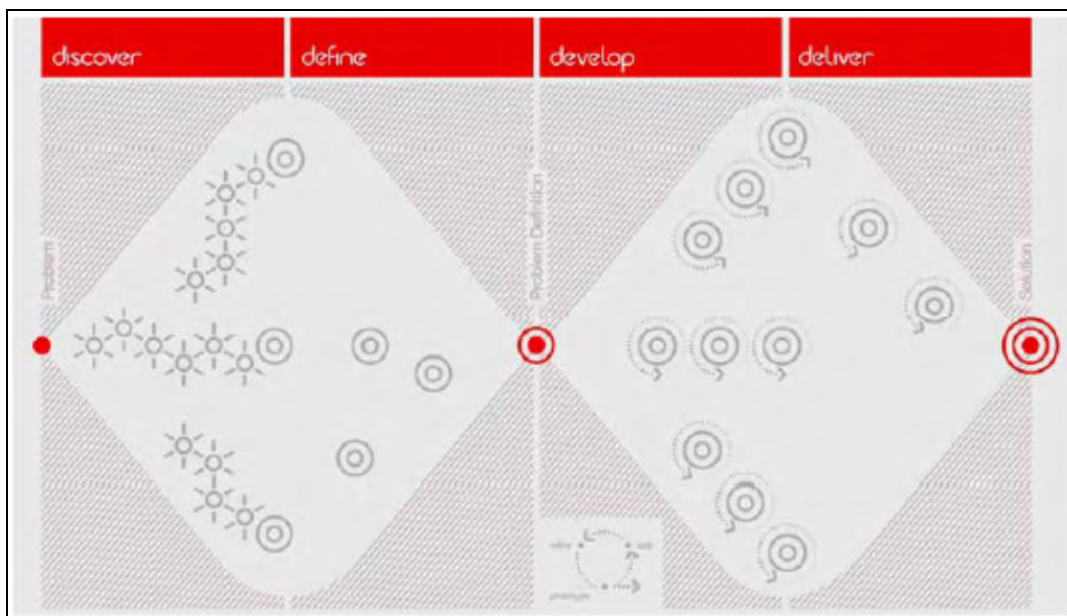


Figure 2.15 Design Council's 'Double diamond' model of design process

The model consists of four phases: discover, define, develop and deliver. It emphasises the discovery phase as, 'one of the most critical, and one which makes best use of the designer's knowledge and skills' (Design Council 2007, p18). This has resonance with other models of NPD and the design process within them (Ulrich & Eppinger 2003, Press & Cooper 2003, Pugh 1990).

Another example of an integrated approach can be seen in the work of Lawson & Dorst, who describe practice as a, 'negotiation between problem and solution' (Lawson & Dorst 2009 p40). Lawson (Lawson 2006) sees design thinking as a complex set of dependencies, analysis, synthesis and evaluation, which work together to inform the problem/solution evolution (Figure 2.16):

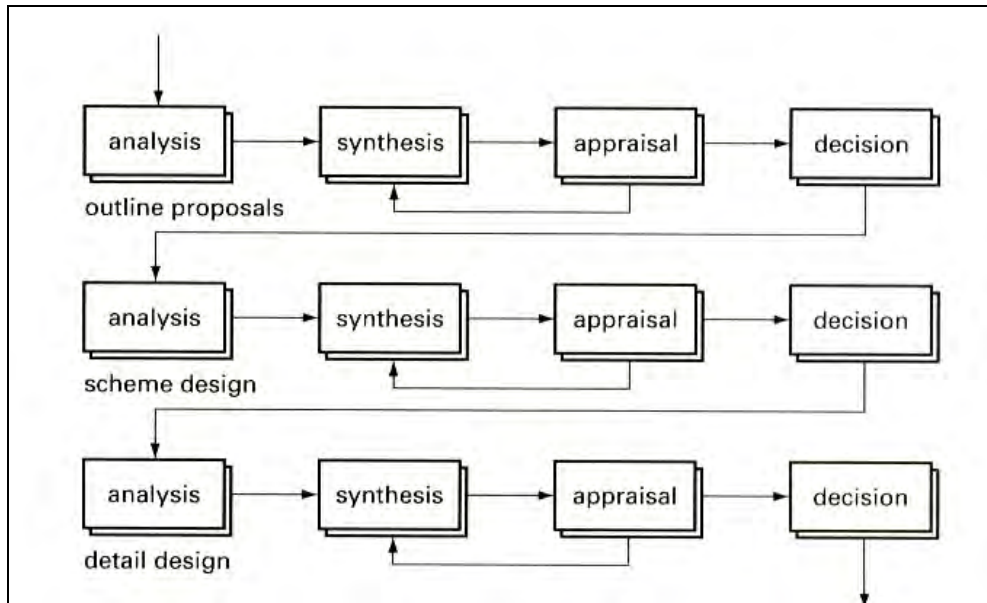


Figure 2.16 Lawson's model of design thinking

2.13 Modelling NPD and Industrial Design

A review of literature of the NPD process, and industrial design's place within it, has identified three types of model. First a staged approach progressing through a number of linear stages to arrive at a design outcome. Second, models suggesting iteration between stages, indicated by feed-back loops and arrows. Finally, integrated models indicated a co-evolution of the search for solutions and an understanding of the design problem. Within the integrative model, design activity is performed in stages that loop and iterate to finally arrive at design specification. Table 1 illustrates the three model types and their key characteristics.

Models of Process	Type of Model	Terms to Describe stages of Industrial Design Process
Archer, B	Linear three stage model of design process.	Analytical Phase
		Creative phase
		Executive Phase
Ulrich & Eppinger	Five stage model of NPD, including three phases of industrial design activity	Concept development
		System-Level design
		Detail Design
		Testing and refinement
	Four stages of design activity with	Exploration
		Generation

Cross	feedback loop	Evaluation
		Communication
French	Four stages of design activity with multiple feedback loops and expected outcomes of each stage	Analysis of Problem
		Conceptual Design
		Embodiment of schemes
		Detailing
Roy	Model of NPD including three stages of industrial design practice	Concept design
		Prototype Development and Testing
		Final product or Design Engineering
Pugh	Six stage model of NPD including two stages of industrial design development. Multiple feedback loops.	Concept design
		Detail Design
Baxter	Six stage model of NPD with three stage approach to description of industrial design. Multiple feedback loops.	Concept design
		Embodiment design
		Detail Design
Cross	Circular Eight stage model of design process within problem/solution model of activity	Clarify Objectives
		Identifying opportunities
		Improving details
		Evaluating Alternatives
		Generating Alternatives
		Determining Characteristics
		Setting Requirements
		Establishing Functions
Design Council	Four stage, diamond model of design process	Discover
		Define
		Develop
		deliver
Lawson	Three stage approach to design process with related four stages in design activity.	Outline Proposals
		Scheme design
		Detail design

Table 1 Summary of models of NPD and industrial design process

The industrial design process and its location within NPD may be summarised as follows: First, the final designed outcome is the specification of design intent for

engineering and manufacture which is a final solution to the design problem. The process of NPD and industrial design practice within it is anchored by this requirement as solution ideas are evolved and progressed towards convergence, specification and manufacture.

Second, the evolution of design intentions towards final specification, although concerned with convergence, also requires iteration and divergence. Because of the often ill-defined character of the design problem, designers must experiment and test ideas in order to help understand the 'problem-space'. This is seen in later model as a solution focused approach. The designer experiments and tests intentions, through embodiment in sketches, drawings, models and prototypes, to evolve design ideas and in doing so, better understands and help define the nature of the design problem. Based upon this review of existing models of NPD and the industrial designer's responsibilities (Table 1), a simplified model of the industrial design process is presented in Figure 2.17:

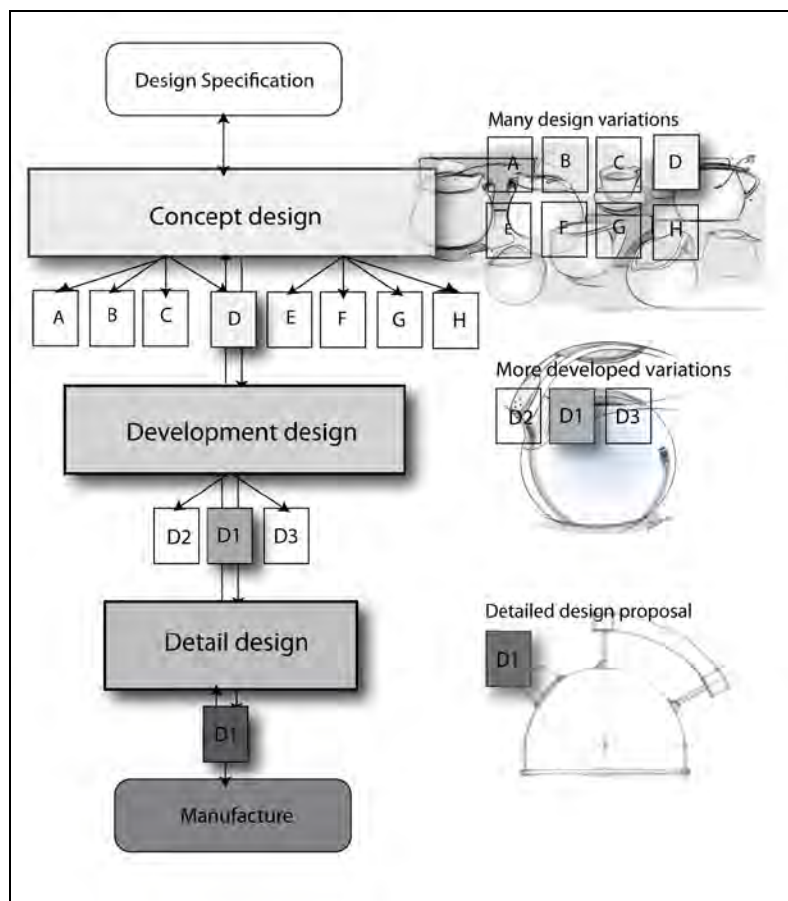


Figure 2.17 Model of the industrial design process

The model (Figure 2.17) describes the design process, as progressing through three stages: concept, development and detail design. As design activity progresses towards the final specification of design intent before manufacture, design embodiment becomes increasingly detailed and specific. However, within this process, design will often iterate between the different stages (represented by the bi-directional arrows between concept, development and detail design). As design progresses, the practitioner will continue to refine design intentions towards a single design solution. This process of refinement is indicated by the reduction of option choices (A-H) as design activity moves through the three stages. Throughout this process, various design tools are employed to embody and communicate design intent. Images of the different kinds of design representations, made through the use of design tools are shown to the right.

The model is by no means prescriptive or intended as a definitive representation of industrial design process. Instead, it is used in an attempt to map out the different requirements of the process as it moves through divergent concept design towards more convergent detail design.

2.14 Three Phases of Design Process

A variety of tools were identified as used in support of concept, development and detail design. The follow section discusses the three generic stages of the design process (Figure 2.17) to review the design tools often used at each stage. The aim of this review was to identify relationships between the stage in process and the types of tools used.

2.14.1 Concept Design

Concept design often comes after a specification phase (Ulrich & Eppinger 2003 p98). These specifications constitute the description of what is often, an ill-defined problem (Cross 2007 p102). Concept design is described by French (in Cross 2008 p31) as a phase in practice which, 'takes the statement of the problem and generates broad solutions to it'. As a result of the often poorly defined design problem, this initial stage of conceptualisation is critical to early design development. For it is through conceptual exploration that solution ideas are generated and the problem defined (Cross 2008 p10).

Haller and Cullen (2004 p94) illustrate the exploration and definition of the problem in the design of a sports headset for Motorola. They describe the start of concept design as a process of brainstorming a variety of solution ideas through their embodiment as concept sketches. These were then refined by the design team to arrive at a group of concepts to take forward to develop further (Figure 2.18):



Figure 2.18 Refined concept sketches of Motorola headset

Concept design is characterised by an open, divergent approach. Designers use this lack of certainty, inherent in the incomplete nature of solution ideas, to allow a wider exploration of the problem through the embodiment of less certain solutions: ‘good designers characteristically have incomplete and possibly conflicting ideas as a matter of course, and allow these ideas to coexist without attempting to resolve them too early in the process’ (Lawson 2006 p154).

This exploration of intent during embodiment is seen in Behar’s (in Hudson 2008, p34) use of sketching to, ‘determined the basic aesthetic of the unit.’ Behar describes the embodiment of ideas as sketches to explore research findings where, ‘Early sketches followed through research of the Bluetooth headset market’ (Figure 2.19).

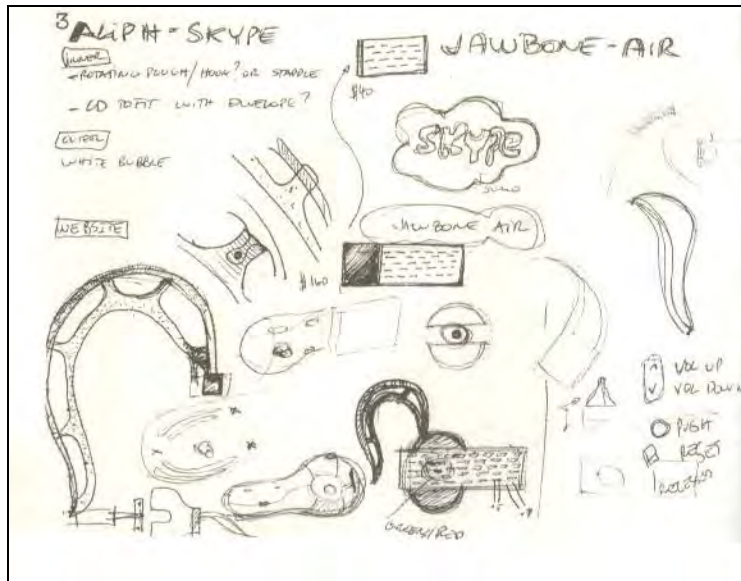


Figure 2.19 Initial concept ideas as sketches by Behar

Concept design is concerned with the initial exploration of the design problem through the embodiment of solution ideas that leave room for interpretation. To do this designers require design tools that allow the quick and dynamic embodiment of intentions. Sketching and sketch modelling (the three dimensional embodiment of ideas using foam, card or clay) are often employed. Hudson illustrates the use of models and sketches when discussing the design of a mixer tap (Hudson 2008 p66). The designer, Lorenzo Damiani, describes his use of rough sketches, exploring early solutions followed by a, 'raw working model using an industrial plastic pipe and adhesive tape'. Hudson (ibid) describes how Damini used the front and back of a rail ticket, the one used to visit the client for the first time, to sketch out his initial concept ideas (Figure 2.20):



Figure 2.20 Damini's sketch on the back and front of a rail ticket

During concept design the designer focuses not only upon the overall concept, but will already be considering detail such as part architecture, materials and manufacture (Cross 2007 p23, Lawson 2006). Concept design tools are required to facilitate the investigation of concurrent thinking, that is, they are effective in support of the embodiment of overall design concepts; the product's aesthetic, but are also used to focus on detail (Press & Cooper 2003). An example of the exploration of detail during concept design is again made by Hudson's (Op cit, p.40) description of the design process of Behar's desk lamp. Behar made a series of sketches to, 'address the way the upper arm attaches to the lower to allow maximum flexibility; others developed a hinge to attach the blade to the base' (Figure 2.21):

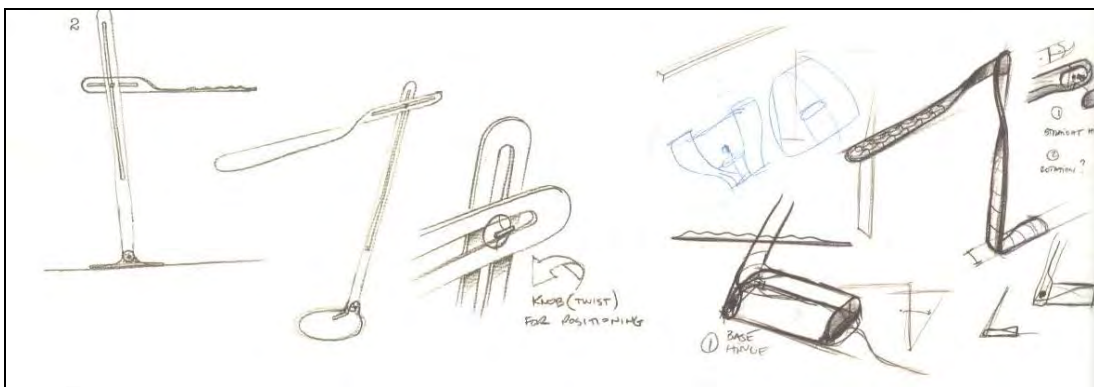


Figure 2.21 Sketches by Behar used to explore design detail during concept design

The output of concept design is the approximate description of the form, function and features of the designed artifact (Ulrich & Eppinger 2003). Sketching and sketch modelling are tools often used for the embodiment of concept ideas (Cross 2008, 2007, Ulrich & Eppinger 2003). Design solutions are considered by all stakeholders in a process of selection, after which one or more concepts will be taken forward to be development and refined (Ulrich & Eppinger 2003). As with development and detail design, although concept design requires an open, divergent approach to effectively explore the design problem through the embodiment of solution ideas, consideration for detail and design convergence is often seen in design embodiment.

This concurrent divergent/convergent exploration can be seen in the design of a desk microphone for the computer peripherals manufacturer, Labtech (Haller & Cullen 2004 p78-81). Designers sketched ideas during a brainstorming session, resulting in some 100 concepts. These were then narrowed down by grouping solution ideas around previously established common themes or attributes (Figure 2.22):

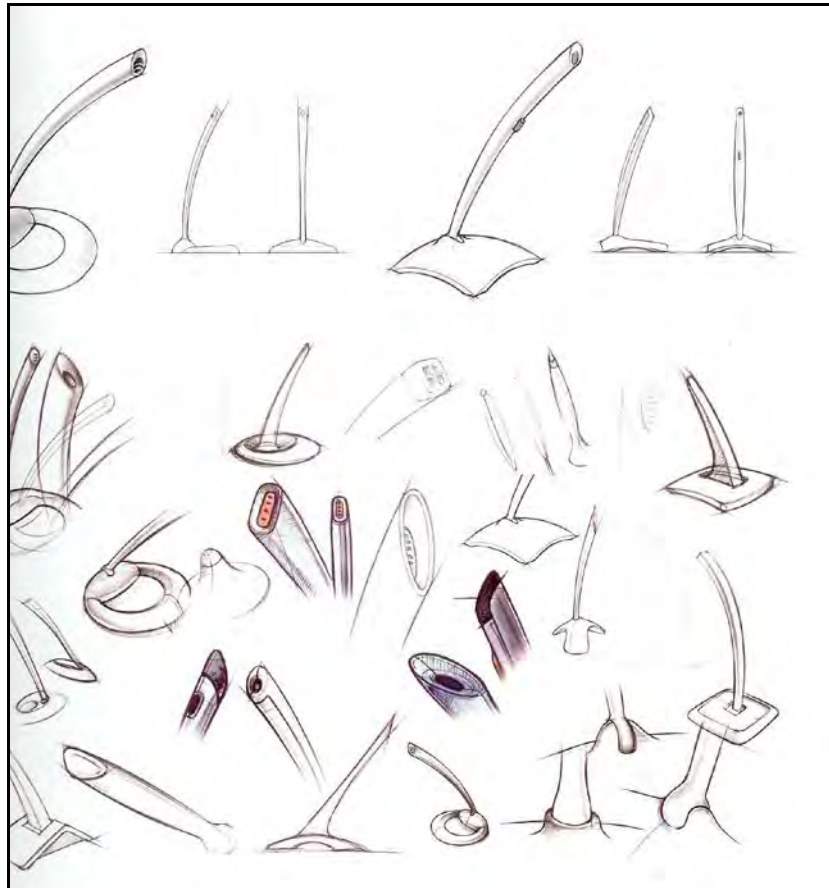


Figure 2.22 initial 'brain-storm' sketches for LabTech digital microphone

This narrowing of solution proposals was followed by the selection of six concepts which were further defined through their embodiment as foam models and 2D graphic illustrations. The six were presented to the client for the selection of one to take forward to develop further (ibid). This design convergence, through selection of concepts, was also identified in Haller and Cullen's (Op cit, p.88) description of the design of an optical transceiver light where, 'in the concept exploration phase, a team of three designers sketched concepts'. This was followed by the selection of three concepts which were then embodied as 3D CAD models and presented to the client for approval and further development as concept design moved in to development design.

There is some difference in the way terms are used to describe the boundaries of the three stages in process: concept, development and design; how far each runs into the other. Pugh suggests the outcome of concept design must be, 'a complete concept(s) engineered to an acceptable level to establish its validity...this will usually take the form of a layout or scheme drawing' (Pugh 1990 p99). Others indicate the outcome as less

specific, sketch models, worked-up concept sketches and possibly renderings (Ulrich & Eppinger 2003), indicating different approaches taken to the design process.

However, concept design is defined by its divergent character, required for an open approach to help generate concept solutions and start to define the design problem. Tools that allow the designer to investigate the problem in a fluid, open way seem most effective at this stage in the design process. Although industrial design practice moved towards convergence, divergent concept design is critical in the exploration of solution ideas.

2.14.2 Development Design

Development design also termed embodiment design (Baxter 1995), is the stage in the design process where conceptual ideas are evolved through a more structured design activity:

Embodiment design takes a set of functional and styling principles (the outputs from concept design) and develops them to the point at which a full working prototype is (or could be) made.

(Baxter 1995)

The aim of development design is to further evolve concept ideas, moving the solution closer through more detailed specification of design intent. Concepts are developed and tested to evaluate their potential as proposed solutions, 'the main difference between embodied design and concept design...is the introduction of a significant measure of product testing and evaluation' (Op cit, p.294). Designs are worked up in greater detail for the purpose of making a final decision to take forward (Cross 2008 p32).

Pugh's model of NPD omits a development phase (Pugh 1990 p9). Instead concept design describes a process which leads to a more detailed outcome: 'the complete concept(s) engineered to an acceptable level to establish its validity' (ibid). Blessing also (in Visser 2006 p133) presents two stages coming after design specification; conceptual design and detail design, but suggests detail design is often divided into two separate phases: 'Often [the detail design stage] is divided into embodiment design, in which the concept is developed resulting in the final layout, and detail design in which every component is fixed in form and shape'. Ulrich and Eppinger (2003 p15) describe a system-level design phase coming after concept and before detail design

that aims to, 'generate alternative product architectures, define major subsystems and interfaces and refine industrial design'.

The movement from concept to development design, using different tools for a more detailed evolution of design intent is seen in Haller and Cullen's (2004 p34-37). Sketching and sketch modelling were used in consultation with the client to narrow down solution ideas (ibid). These were then further developed through the use of 3D CAD software and rapid prototyping to explore and further define part geometry (Figure 2.23):

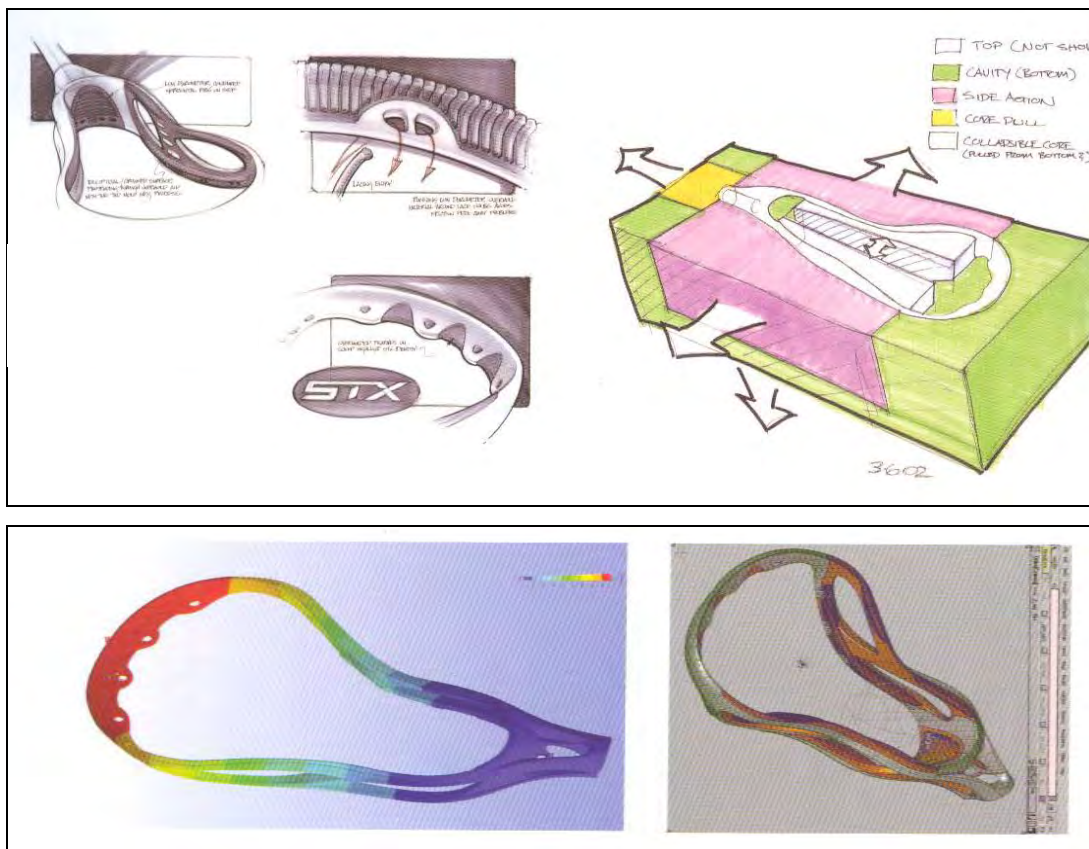


Figure 2.23 The use of various tools during development design

As the designer evolves concept ideas, different tools are used to support design development. Notable is the increasing use of CAD software and prototyping technology as practice increasingly focuses on detail (Ulrich & Eppinger 2003).

Hudson (2008 p172) describes Propeller Design's use of various tools to support different phases in design practice through a case-study of the design of a multi-media console. Propeller employed first sketching and then sketch models to conceptualise

design intentions. At the end of concept design, ideas were embodied using 3D CAD models presented to stakeholders. Later, CAD drawings were used to explore design detail, product architecture and component fit (Figure 2.24):



Figure 2.24 Propeller's use of sketches and a prototype

The outcome of a development phase is often the embodiment of design intentions to present as proposals to stakeholders in greater detail, 'to cover each and every aspect of the product...the outcome will be a single design proposal, even though some aspects of the design may not yet be fully thought out' (Pipes 2007 p130). A characteristic of development design is its increasingly structured approach to communication as practice becomes concerned with the definition and communication of more specific design details: 'communication of design information becomes increasingly important as the design becomes more detailed' (Op cit p130). Press and Cooper (2003) describe the use of digital models to communicate design intentions in parallel with the evolution of design specifics.

Iteration, between concept and development design, is seen in Hudson's (Hudson 2008 p172) description of Propeller's design process. Initial embodied of design concepts were made through sketching. Simple CAD models were also used to, 'make sure that the idea, form and concept are transferable from 2D to physical reality' (Figure 2.25). Design evolution and convergence was achieved through periods of iterative divergence through sketching followed by more detailed convergence using 3D CAD.

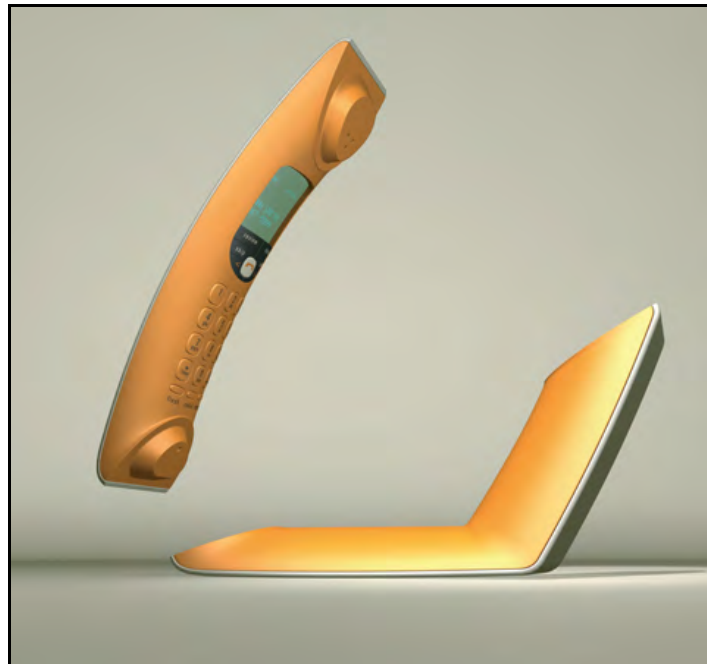


Figure 2.25 Simple CAD model for use in proof of concept

This development of design ideas using different design tools is shown in Haller and Cullen's (2004 p160-163) description of the design of a wrist watch (Figure 2.26). Initial exploration of concept ideas, through sketching, gave way to the use of more detailed graphic illustrations, exploring individual concepts in more detail.

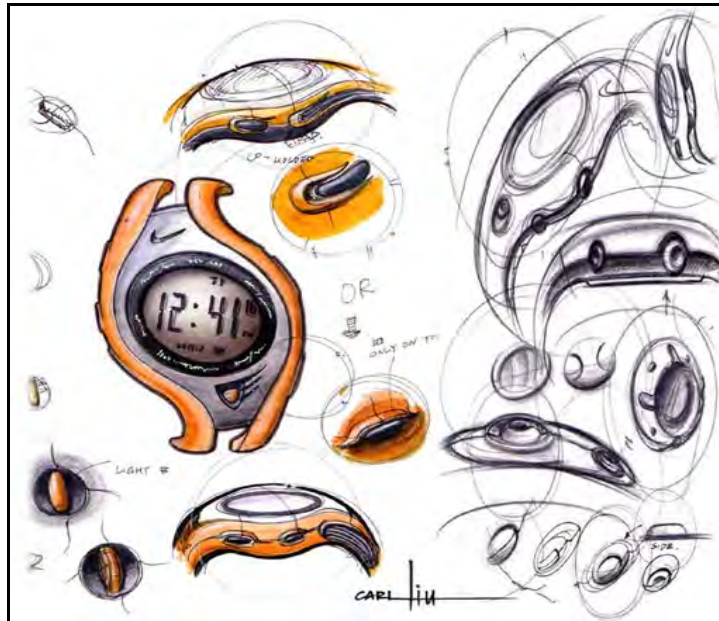


Figure 2.26 The development of initial concept sketches to evolve design proposals

These sketches were followed by the embodiment of intentions using other tools: wax models to assess size and shape, colour renderings to develop aesthetic, 3D CAD models, followed by rapid prototypes, employed to assess strength and rigidity.

2.14.3 Detail Design

This more constrained phase of practice requires design solutions to be embodied in specific detail as design becomes increasingly focused on the manufactured outcome: 'The product's component parts and sometimes even the tooling required to manufacture must be depicted accurately and unambiguously' (Pipes 2007 p157). Detail design involves the movement of solution ideas from an embodiment of detail towards the exacting communication and specification of parts for final testing and manufacture: 'We are now at the end of the design-to-manufacture process for this particular job and the product (once merely a sketch on the back of an envelope) is away being fabricated' (ibid). The search for solutions has moved from the conceptual front end of practice (Cross 2008 p195), to converge upon a detailed solution proposal.

The extent to which the industrial designer remains responsible for detail design is indicated in Haller and Cullen's (2004 p88) description of Teague Design's involvement during specification for manufacture: 'shelled CAD files with parts breaks and accurate surfacing to their [the client] engineering team to use as a starting point for the detailed part design' (Figure 2.27):



Figure 2.27 Shelled CAD model for use in support of engineering

The use of digital CAD tools to specify design intent is now prevalent in design practice: 'in many industries the use of CAD is adopted at the detailed design phase' (Press & Cooper 2003 p143). Detail design is concerned with final specification, although during concept design the industrial designer must consider the detail of the concept, its manufacturability, as well as overall form and aesthetic. During detail design, the overriding priority is manufacture, 'A very large number of detailed points usually need to be decided, and the very precise work of detailed drawing, calculation and testing is carried out' (Lawson & Dorst 2009 p23).

This testing and refinement can be seen in Insight Product Development's design process (Haller & Cullen 2004 p100). After conceptual and development design, a final prototype was produced, 'The team evaluated each one on fit and finish'. Following this, industrial designers and engineers worked together on a final design specification, through embodiment as 3D geometry that, 'met all production concerns while maintaining design intent' (ibid p100, Figure 2.28):

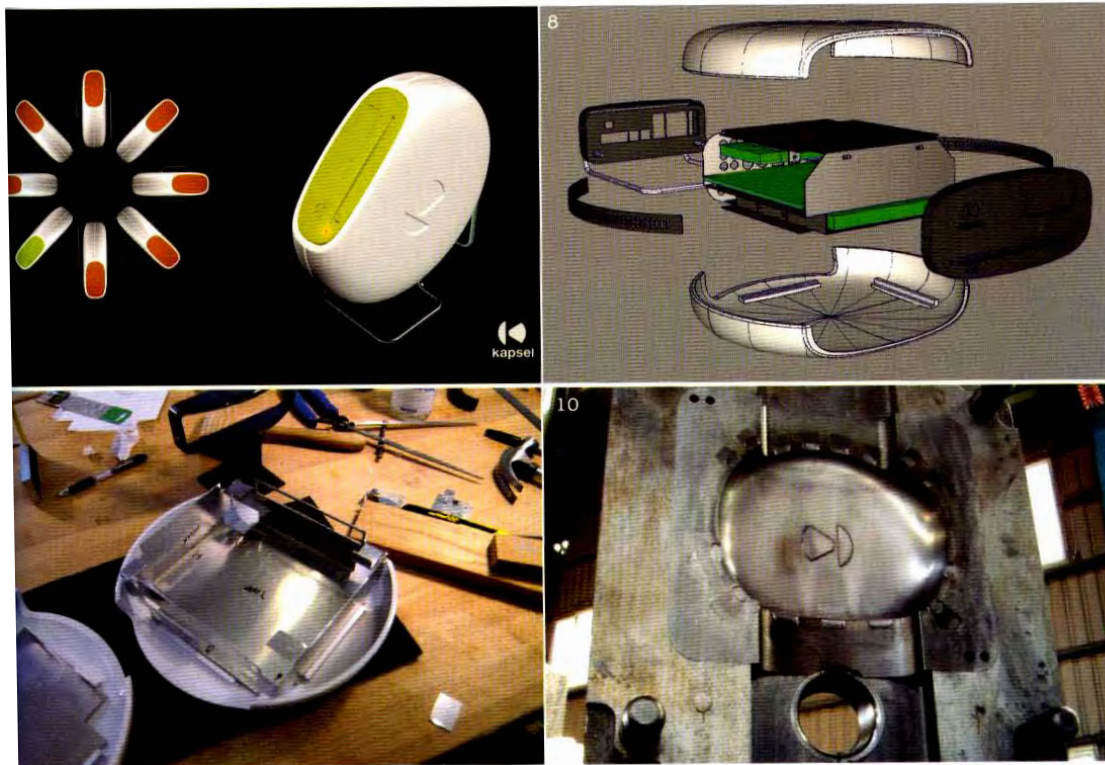


Figure 2.28 Use of CAD in collaboration with engineers and the subsequent prototype

Detail design is characterised by a further structuring of design proposals. This then constrains design practice as the realities of the manufacturing process are worked through:

As we move from concept design, through embodied design [development design] and into detail design, the design principles become progressively more specific to the materials and manufacturing processes involved.

(Baxter 1995)

Ulrich and Eppinger (2003 p15) describe the detail design phase as, 'specification of the geometry, materials, and tolerances of all of the unique parts in the product and the identification of all of the standard parts'. Powell speaks of design as focused upon the definition of, 'each and every aspect of the product' (Powell 2007, accessed 04.03.08).

A detail design stage may involve a handover to engineers in order that they define design for production (Pipes 1990). However, the introduction of ever more powerful digital tools has allowed the industrial designer to play an increasingly influential role in detail design. Because detail design is concerned with the exact specification of design

intent and the unambiguous, structured representation of the design solution, a key characteristic of design embodiment, during detail design, is the communication of specificity for manufacture. At this stage, the design proposal is moving towards full definition and consideration turns to detailed specification.

Japanese designer, Toshiniko Sakai, when commissioned to design an MP3 player for Yamaha, indicated the role of the industrial designer in product engineering (Hudson 2008 p190). Sakai used a combination of different design tools, 3D CAD, physical models, detail sketch work and prototypes to clarify and progress problem areas during development and detail design. The designer remained involved in the design process up until manufacture, being actively engaging in the resolution of component detail specification, 'CAD drawings passed backwards and forwards between Sakai and the client's engineers to address the manufacturing processes and to refine design' (Op cit). When asked of his motivations for the involvement Sakai cited a requirement to understand and take control of engineering to maintain design intent (personal communication). Figure 2.29 illustrates Sakai's use of 3D CAD and prototypes to explore design detail:



Figure 2.29 Sakai's CAD drawings of engineering detail

Detail design as the final phase in the process of industrial design, aims to propose a specific solution to an often 'ill-defined design problem' (Cross 2007 p23-25). Because of the ill-defined nature of the problem and the almost limitless possible solution proposals that may emerge, the design of the artifact ends not because the solution has been found, but rather the chance of significant improvement to the proposal seems small given constraints of the project; time and finance (Lawson 2004).

The movement between concept, development and detail design indicates the convergent nature of industrial design practice. The stages in process also suggest the different ways that a designer must work at different times, using various tools to support design activity. These stages are, however, not prescriptive but are required to aid understanding and develop knowledge of the design process and tool use: 'It is for the sake of clarity, convenience and understanding that we make these *arbitrary* stage or phase distinctions' Pugh (Op cit: 101).

Chapter Summary

In this Chapter the capacity to design, to think ahead and consider what may be, was described as a distinct human ability. However, this research concerns itself with those who design for others, the design practitioner. Design research can be described as focused on two distinct areas of study; the social and cultural influence of design and the study of design practice. This study explores the practice of industrial design.

The history of industrial design can be traced back to its roots in industrial revolution and the separation of craft. From a separation of design from production emerged a requirement to model or specify design intent prior to a process of manufacture. It is the requirement of the communication of design intent, through the use of design tools, that is the focus of this thesis.

Industrial design may be located between design as art and as engineering. Industrial design is concerned with the specification of a design solution prior to manufacture. The industrial designer, more so than the industrial design engineer, influences the form and aesthetic of the designed artefact but must also consider engineering and manufacturability. Within these constraints the designer makes use of design tools to embody, propose, explore and evolve design intent.

Industrial design practice can be described, within a process of New Product Development, through a simplified 3 stage model of the industrial design process: concept (stage 1), through development (stage 2) and into detail design (stage 3) coming prior to manufacture. Within this process Industrial designers explore an often ill-defined problem through the generation of solution ideas. Concept design is the divergent, front end of studio practice where an overall or general approach to the generation of solution ideas is required, but with consideration for design detail and manufacturability. Concept design is characterised by the generation of ideas in order to explore the design problem. Design embodiment is often fluid and necessarily lacking detail. During development design, concept idea(s) are considered and further refined to evolve design intentions. A greater focus on part architecture and assembly characterises a detailed stage in the design process. Detail design involves the final specification of the design solution prior to production. Unambiguous design specification is required. Various design tools are used to support these 3 stages of the design process.

Chapter 3: Tools of Design Embodiment and Design Activity

Introduction

A tool is an inanimate object and not a tool until it is used as such to achieve a purpose. This study uses the term design tools of embodiment to describe the processes through which design intentions are embodied and communicated (i.e. sketching, 3D CAD modelling, rapid prototyping, sketch modelling, graphic illustration), and the media through which this design embodiment takes place, the tool-in-hand (a pen; CAD modelling software of various kinds; a graphics tablet). The tool-in-hand and the process of design embodiment may be seen as separate. However, the tool-in-hand and resulting design embodiment are critically related. As the tool influences the character of embodiment which, in turn, informs the ways embodiment is used to understand design intent.

This Chapter discusses design tool use in terms of the influence of the design process, the role of reflection-in-action (Schon 1983) and the character of design tools. This is followed by a review of literature on the use of analog, digital and emergent hybrid tools during industrial design practice. Activity theory is then presented as a framework to underpin the study of design tools. This is followed by a definition of design tools of embodiment that draws on their use in support of design activity. At the end of the Chapter a Model of Design Activity and Tool Use is presented as a framework for the investigation of tool use during studio practice (Chapters 7 & 8).

3.1 Tools of Design Embodiment and the Design Process

Industrial design is concerned with the vast array of goods manufactured by serial or mass-production methods...The task of modern industrial designers is to produce a plan and specification of a form or mechanism for large-scale production.

(Heskett 2002 p55)

Industrial design is necessarily tied to the manufacturing constraints that dictate the future production of any concept idea. And so design embodiment, mediated through the design tool, must consider the necessity of manufacture as proposals are embodied. As long ago as 1940, Van Doren (1940) described this relationship in terms of the industrial designer's responsibility for the embodiment and communication of a design proposal that both satisfy the requirements of the manufacturing process, and be well received by stakeholders:

Its goal is to achieve forms which are assured of acceptance before extensive capital investment has been made, and which can be manufactured at a price permitting wide distribution and reasonable profits.

(Van Doren 1940)

The industrial designer's role also includes the adding of value to a product within the constraints of manufacturability (Tovey 1997 p9). Industrial design must add to the product's desirability, its perceived quality, increasing its competitiveness in a crowded marketplace and improve the product's chances of success, but the designer must also consider this desirability within the context of manufacture (ibid). Within these competing requirements, designers use a variety of tools to embody, communicate their design intentions.

The activity of embodiment of design intent is influenced by the stage in process in which the activity is performed. Discussion of the use of tools in support of practice often takes an iterative but staged approach to consider the relationship between the requirements of practice and tool effectiveness (Baxter 1995, Ulrich & Eppinger 2003, Cross 1992, Pipes 2007, Powell 2007, Pugh 1990). A common thread within these

studies is the discussion of tools in terms of a dependency upon stage in practice: from a divergent front end of practice to the refinement of design proposals towards manufacture (see Chapter 2).

Dorta et al (2008) considers the use of a variety of tools to embody design intentions for specific design tasks. These tasks relate to the purpose of studio practice at a given time, i.e to conceptualise, develop and/or detail design proposals. A distinction is made between concept design tools and those used during design development (Tovey 1997). During concept design, designs are presented as a number of alternatives through sketch embodiments. As practice moves towards a development stage, detailed concept ideas are evaluated through the use of prototype models and digital 3D visuals. The various tools of embodiment used to support the stages in process will relate to various requirements of practice: conceptual sketching during concept design practice: presentation drawings and illustrations during development design and the unambiguous representation of design detail through detailed engineering drawings prior to manufacture (Pipes 2007).

Design embodiment during concept design is often more ambiguous, using sketching and sketch modelling to support this conceptual stage (Cross 1992). Development design is characterised by embodiments used to communicate design intention to others, with the aim of further defining the design proposal(s). These embodiments often take the form of presentation drawings, 3D CAD models and prototypes (Pipes 2007). Detail design is concerned with exact specification of design intention prior to manufacture, with the designer embodying design intentions using engineering drawings and high fidelity prototypes to communicate intent in detail (Dorta et al 2008).

Goel (1995, p20) describes the relationship between design tool, the influence of the stage in practice and the kinds of design embodiments required:

The purpose of the representation, its place within a process of design development, influences the kinds of representations constructed through the use of design tools.

(ibid p20)

Design activity is influenced by a consideration for the kinds of design embodiments required at given stage in design practice and the various purposes the tool is put to in

order to meet these requirements. In this way, design embodiment and tool use has a fundamental relationship to the various requirements of the design process as design progresses from an open conceptual stage through to the final specification of intent prior to manufacture. Although thinking about design tools in terms of their ability to support a given stage in practice is a useful starting point, as well as the pragmatic considerations of the design process, tool use must also include the influence of both the tool's character (tool-in-hand) and the designer's own idiosyncratic use of a given tool (designer influence). How then, do these influences play into the relationship between the design tool and the design process, and how might the designer's own idiosyncratic studio practice influence the tool process relationship? To answer these questions we must shift our attention away from the design tool towards the designer.

3.2 Tools of Embodiment and Reflection-in-Action

The notion of design activity as a process of reflection-in-action has been well documented (Cross 2007, Cross 2008, Goel 1995, Jonson 2005, Stolterman et al 2008, Lawson 2006, Schon 1983, Tovey, Porter et al. 2003). A number of terms were identified as used to describe the designer's own reflective design activity, 'conversation with design activity' (Lawson 2006 p265), 'Design talk-back' (Schon 1983 p79), 'visual design thinking' (Goldschmidt 1994 p160). These studies describe design practice as influenced by the designer's construction of and reflection upon their own embodied design intentions. The physical embodiment of the designer's own thoughts mediated through the use of design tools.

Schon's (1983) study describes the ways the designer engaged in a conversation with the physical representation of intentions through drawings. He describes design practice as a process of, 'reflection-in-action'. Within this process the designer engages in conversation with the 'materials' of the situation:

Sometimes he makes the final product; more often, he makes a representation – a plan, program, or image – of an artefact to be constructed by others. He works in particular situations, uses particular materials.

(Schon 1983 p78)

The practitioner will reflect upon and re-evaluate design intentions through a conversation with the embodiment of their design ideas. These reflections then provide

momentum for the designer to access and evolve design intent in what Schon terms, 'design moves'. These moves iterate, through mediating design tools, in a progression towards commitment, 'thus there is a continually evolving system of implications within which the designer reflects-in-action.' (Schon 1983 p103).

Schon (Op cit) says less about the implications for reflection-in-action for the use of different kinds of tools and media. However, all design 'moves' are described as having an element of unpredictability. This unpredictability is the result of interaction between designer and a process of embodiment of design intentions, 'he can never make a move which has only the effects intended for it. His materials are continually talking back to him' (Schon 1983 p101).

The design process progresses intent towards a final proposed solution. Within this process, design shifts from exploration (concept design) to commitment (detail design), 'from the stance of tentative exploration to one of commitment' (ibid). Schon (Op cit p101) does not describe the influence of the kinds of embodiments afforded through the use of various tools, and what their use may mean for reflection-in-action as practice shifts from exploration to commitment. He also does not consider the influence of the designer's idiosyncratic use of and reflections upon the embodiment of design intentions in any detail, although he does identify confidence as an attribute of the more experienced design practitioner, in understanding and moving in reaction to the, 'conversations with the situation'.

The notion of conversation has since been further developed, most notably in the work of Lawson (2004 p84), who describes a two-way conversation through which the designer employs design tools to embody and reflect upon design ideas. Lawson (op cit, Purcell & Gero 1998) considers the ways in which these conversations inform an exploration of the design problem through the tangible embodiment of solution ideas as sketches and the use of 3D CAD. His discussion of design embodiment through 3D CAD indicates the influential role the design tool may have on a designer's studio practice, describing the ways CAD may constrain conversation: 'a halting clumsy process that more closely resembles the assembly of a sentence in a foreign language' (Lawson 2004 p70).

Dorta et al (2008) point to the reflective nature of design practice with a focus upon the influence of design embodiment and how this relates to the changing requirements of

practice as design progresses. He discusses a process where designers use externalised models of proposed design solutions to interact with mental images. Dorta et al (ibid p122) suggests these 'models', as design sketches, drawings and physical prototypes, are used as interaction between design thoughts and design activity. This interaction informs a process where the externalised design embodiment of ideas results in unexpected developments. Schon's describes this interaction as 'talk-backs' and 'conversations with the situation', (Schon 1983 p79).

Cross (2008 p21) discusses a solution-focused approach to reflection upon design intentions, and how, through embodiment and reflection-in-action, the designer shapes an often ill-defined design problem through generation of solution proposals. These proposals are then reflected upon and further developed through a cyclical process, often iterative, to finally converg on a design solution (ibid). Within this process, design tools are used to construct design embodiments of solution intentions which are then reflected upon to progress design intent (Visser 2006 p115).

Powell (1985) describes the critical relationship between design tools and the designer's own ability to employ reflection-in-action to effectively support thinking during the various requirements of studio practice:

If you can communicate your design ideas well to others, you are also better equipped to communicate them to yourself; you can, so-to-speak, hold a conversation with yourself as you work, shifting quickly and easily from drawing to drawing as an idea develops, and keeping pace with the speed of your own thinking.

(ibid p6)

Through a process of design embodiment, the designer reflects upon the physical embodiment of design ideas during the design process. These embodiments of design intent take many forms; a sketch, a graphic illustration, 3D CAD model, prototypes of various kinds and sketch models (Pei et al 2008 p8). It is the process of design embodiment, supported by the designer's use of various digital, analog and hybrid tools that is the focus of this research. Reflective design activity indicates the relationship between design tools and their use by the designer in support of practice. The tool's character and the designer's idiosyncratic use influence design embodiment and the kinds of reflections made.

3.3 The Designer and the Character of Design Tools

A range of design tools are used to support the different requirements of practice as design progresses, often iteratively, towards the specification of design intent and manufacture (Pipes 2007). The industrial designer will use design tools to facilitate both a personal activity of reflective design and to communicate proposed ideas; describing and explaining design intentions in collaboration with other designers, design engineers and stakeholders (Nelson and Stolterman 2003 p171).

A number of studies have explored the character of design tools in terms of their effectiveness in support of practice. Goel (1995 p193) compared design embodiments as design sketches and embodiment through the use digital graphics software to investigate its ability to support a divergent, conceptual design activity. The study compared hand sketching with digital CAD software in order to explore the ways in which the character of the two tools influenced the embodiment of design intent (Op cit p194). Goel speaks of an ordering of embodiments, when sketching, that allows a 'fine-grainedness' in the kinds of embodiments made. This, he suggests, helps to ensure that exploration of a variety of different possibilities was maintained. Goel's (Op cit p193) protocol indicated that the highly ambiguous nature of hand sketching allowed a wider exploration of the design problem through the generation of less fixed design embodiments. This wider exploration was seen as providing the context for reducing the crystallisation of design ideas and limiting early fixation. The research suggested the highly dense, ambiguous character of the sketch in contrast with the less dense and more unambiguous character of digital media. It was these differences that made the two tools of embodiment more or less effective in support of conceptual design practice (ibid). Ambiguity, when sketching, allows the designer to reflect upon and move between design ideas without fixation. The presence of these two characteristics supported the lateral exploration of a variety of design ideas; the ability to move from one design ideas to a variation of the same idea (Op cit).

By focusing on the character of the tool, Goel's (Op cit) study did little to account for the designer's own idiosyncratic tool use or the influence of the different requirements of the design process. However, the study indicates the influence of the tool-in-hand and its the mediation of ideas during design activity.

In other research, Bilda and Demirkan's (2003) comparative study of designers' sketching activity through traditional paper and pencil versus 3D CAD used a protocol to explore the effectiveness of 3D CAD compared to hand sketching during conceptual design. The study suggested that an understanding of how designers work cannot be separated from an understanding of 'how designers think' and that this thinking process is facilitated by the embodiment of design intentions as drawings and other representations. Within this process hand sketching is more effective in allowing the designer to conceive the design problem and produce alternative solution ideas (ibid). However, the influence of the designer's own idiosyncratic attitudes towards tool use is critical, 'Although digital media seems to be inconvenient for the conceptual design phase, this situation depends on designers' designing habits' (Op cit p49).

Jonson (2005 p613) explored the impact of digital technology on how designers think and described studio practice as, 'a matter of generating, developing and communicating ideas, where 'idea' is understood as a basic element of thought that can be either visual, concrete or abstract.' He describes the use of design tools as the media through which abstract or internalised ideas may be given an embodied, externalised form, and so become 'concrete'. Jonson's (Op cit) study compared the use of 3D CAD against hand sketching during conceptual design. The designer participants were required to indicate which tools they used during conceptual design practice through a self-administered survey at the end of each working day (Figure 3.1). Jonson (Op cit) then calculated the amount of time spent using various tools as a proportion of overall conceptualisation time. The (Op cit) study suggested that the designers spent time using a variety of design tools, including CAD, during conceptual design and that sketching, as a proportion of time spent, was not dominant, 'The findings, therefore, challenged two dominant views in the literature. First, that sketching is the primary conceptual tool, and, second, that computing is unsuitable for conceptualisation' (Jonson, 2005 p619). In conclusion Jonson suggests sketching may not be as necessary to concept design as previous studies have indicated (Bilda & Demirkan 2003a, Goel 1995, Tovey & Porter et al. 2003, Suwa & Tversky 1997).

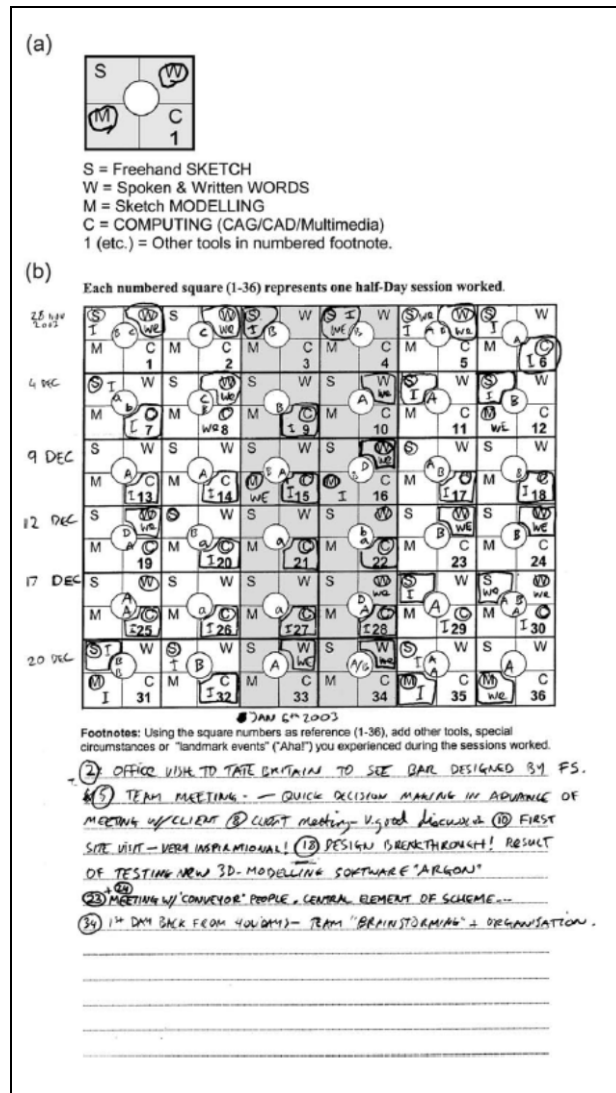


Figure 3.1 Jonson's 'self-completion' method of data gathering

Jonson's study (Op cit) also assessed the influence of the designer's background upon tool use in practice: 'The length of the conceptualisation period varied greatly in the 10 cases reflecting the unique character of each project as well as individual approaches to ideation' (Jonson, 2005 p618). Although citing the influence of idiosyncratic use, the research did less to explore how individual approaches to ideation influences tool choice and effectiveness. Jonson (2005 p622) describes design practice as a, 'sense-making activity' that is not tied to any particular design tool. He concludes by suggesting that it is through reflection upon one's own use of tool's that the designer may more critically engage with design practice and tool use, 'by looking critically at their own ideation process, gained greater awareness of conceptual tools and therefore better understanding of why sketching?' (ibid p623).

Visser, (Visser 2006 p119) uses the term 'construction of representations' to describe a process of design embodiment where the designer uses external, qualitative and imprecise visualised data to interact with their mental images during practice. Externalised design representations require the designer to be in constant contact with them to allow design decisions to be made and the design process to progress (Visser *ibid*). For Visser (2006) a representation may take both an internal and an external form. Internal representations are described as the thoughts and imagination of the designer, external representations as any kind of externalisation of thoughts, drawings or illustrations; but also the written word and speech.

Design embodiment is an interactive conversation critical to the evolution of design intent, 'These interactions, between designer and design representation allow design to progress' (Dorta et al. 2008 p124). Visser, (2006 p14) terms this engagement the, 'cognitive artefacts of design'. In order to deal with design problems the designer must embody the solution proposal through the use of various tools during studio practice: 'the designer makes a solution proposal and uses that to help understand what the problem really is and what appropriate solutions might be like' (Cross 1992).

Stolterman et al, (2008) has also explored relationships between the character of tools and studio practice. He defines design tools as any method, tool, technique or approach that aids practicing designers, 'anything the designer may use to support practice' (Op cit p5). Stolterman et al (2008) describes his study as not an investigation of the intrinsic value of various tools, rather a mapping-out of how designers may think about, appropriate and use design tools during practice.

Our purpose is not to find the best tool for any given activity, but to find an approach that would let us describe and understand the intricate relationship between designers, their activities, and their tools.

(Stolterman et al 2008 p3)

Design tools have characteristics that make them more or less effective in support of a given design activity (Stolterman et al 2008). Stolterman's research presents a framework to understand the complexity of design tool use through a description of core relationships: the 'Tool-in-Use Model'. The model describes relationships between the purposes of design; the relationship purpose has with the kinds of design activity undertaken and the tool's influence upon that activity. These relationships are

described as fully reciprocal, informing the use of tools during studio practice (Figure 3.2):

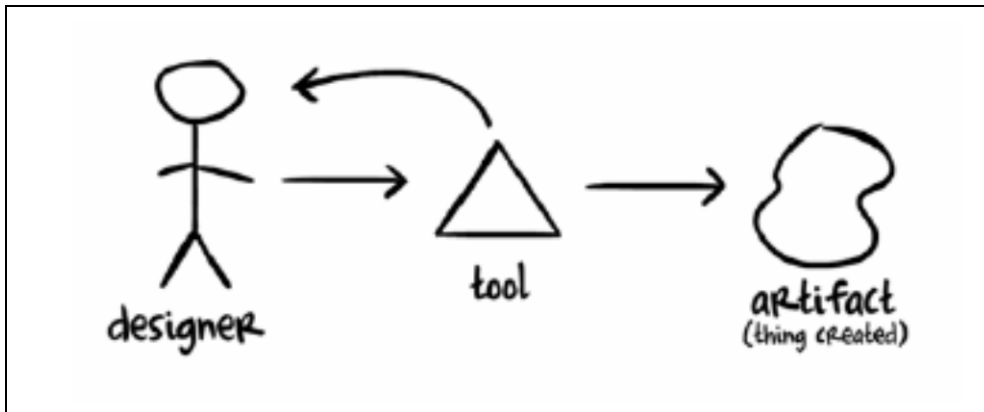


Figure 3.2 Stolterman's et al Tool-in-Use model of design activity

Discussing the influence of the designer upon tool use, Stolterman et al (ibid) suggests they may appropriate a given tool and then consider how the tool may be employed to achieve the purpose of the design activity. The paper concludes with a description of craftsmanship as a driver behind this 'tool-first' approach. For tools to be effective in satisfying the requirements of studio practice the designer must be skilled in their use in order to then understand their affordance and constraints in terms of the various requirements of the design process. However, the ways in which skill and designer expertise influence a tendency towards 'tool-first' or 'purpose-first' choice during studio practice was not developed. Conclusions point to the influence of the designer's idiosyncratic choice and use of tools, but did less to consider the ways that designer attitudes might influence relationships between design purpose, practice, and the tool-first/purpose-first approaches. Instead, the investigation is an attempt to map out relationships between tool use and design practice, suggesting the complexity of tool choice and use within this relationship.

The dependence on the modelling of intentions through embodiment appears to be amplified by the reflective (Schon 1983) and solution-focused (Cross 2007 p101) nature of design activity during the exploration of often ill-defined design problems. The designer must explore the design problem through the generation of and reflection on design embodiments, a co-evolution of solution and problem (Cross, ibid). This embodiment of design intentions is a critical part of studio practice (Goldschmidt 1997, Bilda & Demirkan 2003a, Goldschmidt 1992, Purcell & Gero 1998, Jonson 2005). The characteristics of design tools influence the design embodiments they are used to

construct. Moreover, the design process is an evolution of different kinds of design embodiments (Goel 1995, p93) influenced by the variety of design tools used in their construction (Visser 2006 p159). Design embodiment when sketching, for example may be of more use at the front end of design practice, during conceptual design (Goel, op cit), although this remains dependent upon idiosyncratic use (Jonson 2005). On the other hand, a more constrained form of embodiment is effective at later stages of the design process (Goel 1995 p92).

The influence of the tool's character and its relationship to the kinds of design activity it supports is well established. There is clearly a relationship between the character of the tool-in-hand and its use in practice. However, the researcher was not able to find the same depth of investigation on the relationship between the designer and tool use. The designer's own habitual and idiosyncratic approach to practice and how this then influences tool use and the nature of design activity.

3.4 Analog, Digital and Hybrid Tools

The following section reviews design tools often used in practice and is divided into three parts: analog, digital and hybrid tools. This separation reflects a body of work which compares digital against analog tools (Bilda & Demirkan 2003a, Goel 1995, Jonson 2005, Dorta et al. 2008, Tovey, Owen 2000, Hornecker 2007, Jonson 2005, Coyne, Park et al. 2002). Analog tools are described as tools that do not require digital technologies and are often manipulated using more complex motor skills: hand sketching and hand draw illustrations, sketch model making and other hand crafting workshop practices (McCullough 1997). Digital tools are those that exclusively use digital technologies in the embodiment of design intent through digital media; the increasing variety of CAD software, digital modelling, two and three dimensional illustration and rapid prototyping technologies. Finally, hybrid tools are those employing mixed approaches to embodiment, making use of both complex motor skills and digital media: haptic devices, graphics tablets and the practice of mixing hand drawn sketching techniques with digital media allowing physical interaction with a digital interface.

3.4.1 Analog Tools

The emergence of CAD technologies has not spelt the end of analog design tools. As the strengths and limitations of digital tools continue to find their place within studio practice, sketching and hand drawn illustrations are still widely used (Cross 2007 p54).

Figure 3.3 illustrates the use of hand sketching in support of design practice:

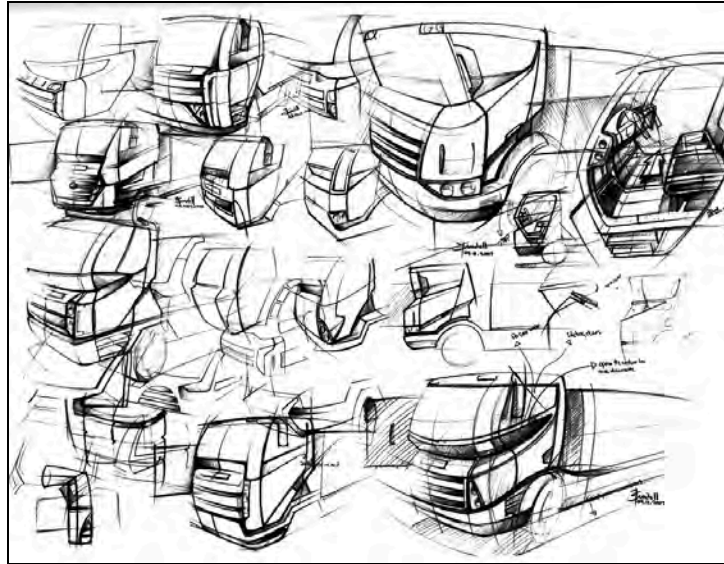


Figure 3.3 Example sketch embodiments often made during concept design practice

Sketching's speed, its dynamic malleability and less committed nature are all characteristics that continue to ensure its effectiveness during concept design (Olofsson and Sjolen 2006 p46-71). As a result of this versatility hand sketching is often cited as effective in support of divergent thinking and a wider exploration of idea (Fish 2004, Lawson 2004, Purcell & Gero 1998). Olofsson and Sjolen (2006) point to the critical role sketching plays in supporting a reflection-in-action and exploration of the design problem, 'The mere acts of formulating a mental image in a concrete way on paper makes it possible for the designer to reflect over the concept at once and almost instantly develop it further into a new concept' (Olofsson and Sjolen 2006 p5).

Sketching's effectiveness in support of studio practice is often described as a result of its ability to embody, 'a fuzzy idea of what could be' (Pipes 2007 p12). The sketch is also critical to practice in its ability to communicate design intent to stakeholders (Pipes 2007 p113). Speed and dynamic change appear dominate in this highly reflective activity where, 'two-way non-verbal dialogue and extreme fine motor control allows us

to process emotion, space, reality, and imagination, and offer it up to ourselves and others in a form that is instantly and universally understandable' (ibid).

In a study of sketching verses digital media Bilda and Demirkan (2003) discuss sketching's ability to support a more explorative design process:

Designers were more effective in using time, conceiving the problem, producing alternative solutions and in perceiving the visual—spatial features and the organizational relations of a design in traditional media rather than digital media during conceptual design.

(Bilda & Demirkan 2003 p49)

The reflective nature of analog hand sketching is critical in support of conceptual design, where the designer's ability to reflect-in-action is employed in the exploration of design ideas, 'the nature of visual thinking as a process, in which ideas emerge through sketching, rather than the view that ideas originate in the designer's head' (Tovey and Owen 2000 ibid p2). Sketching is fundamental in fostering the kinds of thinking seen in conceptual design practice, 'more than an external memory aid; it enables and promotes the kinds of thinking that are relevant to the particular cognitive tasks of design thinking' (Cross 2007 p58).

During concept design it is also common for designers to embody intent through the construction of quickly made physical models (Green and Smrcek 2005). Like the hand sketch, these are fluid, spontaneous, low-fidelity embodiments made using physical craft-based skills and techniques. Green and Smrcek (ibid p324) discuss their ability, like sketching, to allow reflection-in-action (Schon 1983), 'Physical models are an essential tool in developing judgment via critical evaluation and reflection'.

There is a distinction between 3D design embodiment as digitally produced rapid prototypes, digital modelling through computer software and hand crafted models, 'building 3D physical models, or what some people call sketch-models, drawing virtual models and constructing real objects through rapid prototyping' (Green & Smrcek, op cit p324). The hands-on, motor-skill driven approach to design embodiment, seen in the construction of physical models, allows the same kinds of design thinking (Cross, Op cit) or reflection-in-action Schon (Schon 1983) seen in the use of hand sketching techniques (Green & Smrcek 2005). Because design embodiment of physical models

as apposed to rapid prototypes can provide a richer interaction with the embodiment (Dorish 2001, Green & Smrcek 2005), haptic technologies have emerged that attempt to mimic this rich interaction (see hybrid tool below).

The craft-based skills required during design embodiment as conventional models and those digitally constructed also distinguishes 3D CAD modelling and the hand-made model, 'Model making is a tool within the [product design] process that offers either a hands-on or a computerised methodology' (Slack 2006 p88). The ways in which the designer interacts with embodiments through the use of conventional workshop processes compared to 3D CAD tools has also received attention (Dorish 2001, McCullough 1997). McCullough (ibid) suggests the use of 3D CAD constrains the ability of the designer to think-in-action (Schon 1983) and reflect on the embodiment of ideas during the construction of the design representation (Dorish 2001, McCullough 1997). This may be a result of the different skills required when employing analog model making techniques compared to the use of 3D CAD.

Velasquez-Posada (2005) provides a classification for the techniques required when engaged in the construction of handmade models, from the construction of high-fidelity appearance models to sketch models made from polyurethane foam or card. Figure 3.4 illustrates an example of a sketch model from the design consultancy Dyson (Electronics in Schools 2011):



Figure 3.4 Conceptual sketch model, foam, card and 'found objects'

Like sketching, the character of sketch modelling is important to its effectiveness in support of concept design. Speed and dynamic flexibility are critical as the designer explores the design problem through the embodiment of solutions ideas:

In a cost-efficient way; without unnecessary loss of time; using ‘fuzzy’ definitions due to the incompleteness of product definition within the early stages. Non-digital external representations, such as sketches and simple physical models made of paper, wood, wire, Styrofoam etc., meet these requirements.

(Römer & Pache et al. 2001 p478)

Despite the undoubted influence of digital technologies, analog design tools continue to play a role in support of contemporary practice. Evidence of their influence is seen in the emergence of web blogs and tutorials concerned with propagating and exploring approaches to sketching and graphic illustration. Figure 3.5 illustrates a screen-shot from Nugent’s (2011) industrial design sketching blog, idsketching:



Figure 3.5 Screen shot from Nugent's idsketching resource site

Emerging digital technologies continue to place themselves as digital alternatives to analog processes (see hybrid tools below). However, in spite of the many affordances that digital technologies bring to practice, analog tools continue to play a significant role in the embodiment of intent during design activity.

3.4.2 Digital Tools

The use of CAD software is now pervasive, 'giving visual form to an object will more often than not involve the computer and various design packages' (Sass and Oxman 2006).

Although the origin of CAD may be traced to the work of Southerland at MIT in the 1960's, digital technologies first emerged within design practice in the mid 1980s as a means to help prescribe design for manufacture, 'representations composed of detailed technical drawings and rapid prototyping models...to communicate exact and definitive information to build the artifact' (Goldschmidt, Porter 2004 p203). An established relationship between CAD tools and detail design practice is discussed by Purcell and Gero (1998), who note that the kind of embodiments required during detail design are highly structured. Pipes (2007) also takes this position:

Engineering drawing...has one purpose: to communicate a designer's concepts to those responsible for manufacturing the components of the product and assembling them. As such, the drawings must be complete, reliable and, as I keep saying, unambiguous.

Pipes (Pipes 2007 p156)

The ability of CAD to support the unambiguous embodiment of design intentions, specifically and in detail, illustrates how the character of the design tool necessarily relates to the requirements of practice. Digital technologies are effective in support of detail design because of their ability to support the kinds of embodiments required at the stage in the design process.

Digital technologies continue to play an increasingly important role in studio practice, 'One of the most recent issues for 'thing'⁵ designers is the impact of new technologies' (Cooper and Press 2003 p174). Heskett (2002 p192) considers the increasing influence digital technologies have in supporting design practice:

⁵ Press & Cooper describe this 'thing' as a group of design disciplines interested in the design and realisation of material artefacts. These may include: product design, furniture design, packaging design, ceramic design and even automotive design.

It is clear that computers have had a profound, transformative influence as a tool in design, extensively supplementing and enhancing, although not always replacing, existing means of conceptualisation, representation, and specification.

(Heskett 2002 p192)

Figure 3.6 illustrates the use of 3D CAD (Rhino modelling software) in the embodiment and communication of design intent:



Figure 3.6 Example CAD model. Created using Rhino software

Although digital technology has now largely replaced the use of analogue tools during detail design, conceptual design has shown more resistance to the pervasive influence of CAD. Tovey and Owen (2000) discuss the use of CAD in automotive design as prevalent during design development and detailed specification, but less influential during conceptual design. They suggest this is due to the nature of the tool and its inability to augment the kinds of fluid conceptual representations needed to support concept design, 'the styling process falls naturally into two parts: concept design (up to week 4) and design development (thereafter). Computers tend to be used more as styling proceeds, with greatest use after week 7' (ibid p570).

Lawson (Lawson 2004 p71) takes a skeptical position on CAD tools, describing their inability to augment the kinds of design embodiments required during concept design due to their constraints on the kinds of reflection-in-action they afford:

Existing vectoring CAD systems use symbolic representations that do not map well into the internal mental symbolic representations used by designers. As a result working with such systems leads to a less rich mental world since the drawings 'talk back' to us in less suggestive ways.

(Lawson 2004 p71)

Lawson (Lawson 2004) considers 3D CAD modelling as less effective during conceptual design due to its inability to augment the kinds of fluid design embodiments often constructed during an early phase of practice, 'A general common sense account of experience with systems [3D CAD] is that they are not helpful tools to use while in the early stages of designing' (ibid p71). A particularly negative position on CAD's use at the front end of practice is described as it is unable to support a fluid reflection-in-action and instead is more a, 'halted conversation' (Lawson, Op cit p71).

During development design Dorta et al (2008 p125) describes the use of CAD presentation drawings during design practice and the designer's engagement with design embodiments through the use of, 'digital three-dimensional models, drawings and images.' Purcell and Gero (1998 p389) describe the use of realistic design embodiments at a stage after conceptual design as design intentions develop and, 'other more structured forms of pictorial representation, such as plans or sections, become a part of the process.' The literature indicated the use of CAD during concept design is still limited.

A more recent but now well established digital design tool is rapid prototyping. Rapid prototyping uses digital geometry, created through design embodiment as 3D digital models, to produce physical components from digital files. Unlike physical model making techniques, rapid prototyping is exclusively digital. The designer/maker has no control over the production of rapid prototype parts. Data is sent to a rapid prototyping machine which then produces a physical representation. There are, however, many advantages in the use of rapid prototyping over conventional model making processes in terms of time and cost savings, 'time and an ability to embody design intentions using materials and with exacting geometry in support of the communication of design intent' (Evans 2002).

Other advantages include its ability to represent complex forms in an increasing variety of materials. It is often used for the creation of designs as 3D shapes with attention to

material detail, and as a model for production at the detail design stage in practice (Sass 2006 p327). Rapid prototyping is also employed to create representations as high-fidelity prototypes, through the addition of finishing techniques such as sanding and painting. These have the ability to communicate design intent for approval prior to manufacture. Figure 3.7 illustrates the kind of high-fidelity rapidly produced prototype used during user testing, validation by client stakeholders and to maintain design intent during engineering for manufacture.



Figure 3.7 Rapid prototyping offers opportunity for fully functional design embodiment

Rapid prototyping may be used during concept and development design to support design communication and evolution. However, as with the use of digital modelling during concept design, there remains a debate over the ability of rapid prototyping technology to provide the kinds of tactile interaction seen in the embodiment of design intent using traditional, hand-crafted model making processes (Dorst 2006). The following section presents a review of tools that attempt to bridge the gap between digital technologies and their ability to support the kinds of motor-driven, tactile activity seen in the use of analog design tools of embodiment (Horhecker 2007, McCullough 1997, Dorst 2001).

3.4.3 Hybrid Tools

McCullough (1997) discusses a requirement for a more intuitive interactive experience when engaging with digital design tools during practice. This position is centred on an inability of digital tools over their inability to facilitate the kinds of interaction seen when

sketching or modelling using foam or clay (Dorish, 2001, Hornecker, 2007, Ullmer and Ishii, 2001). A more embodied interaction with digital technologies closer to that experienced through the use of handmade models and when sketching is discussed. Drawing from phenomenology and, in particular, the work of Merleau-Ponty (1962), this work suggests that the experience of 'being' is important in our perception of the environment around us as we understand the world through our rich interaction with it (McCullough 1997). The interaction with digital technologies may therefore be described as sensorally narrow, primarily visual and limiting the kinds of engagement supported through its use. This limits the designer's ability to more intuitively use digital technologies in support of conceptual or explorative design activity (Merleau-Ponty 1996, Dorish 2001).

Tools which employ digital technologies, but describe themselves as augmenting the kinds of sensorally rich activities seen in the use of analog tools, have emerged most notably in the development of hybrid tools, such as the work at MIT's Touchlab⁶, and the commercially available haptic interface devices, (Sensable technologies 2008). However, research into the capabilities of haptic technology, in its present form, to effectively support industrial design practice concluded that, although effective in the embodiment of some detail, the device may be less suitable for the kinds of rich engagement experienced when working on the embodiment of form using analog model making techniques, 'it highlighted the capacity to engage in tactile interaction with virtual geometry, but more significantly, demonstrated severe limitations in applying this to industrial design practice' (Evans et al. 2004 p505-506). Figure 3.8 illustrates the kinds of engagement afforded through the use of haptic technologies:

⁶ The Touchlab was founded by Dr. Stinivasan of Massachusetts Institute of Technology. The lab is interested in haptics and haptic technologies; the study of sensing and manipulation through touch. A technology originating from MIT's Touchlab, the literature promoting haptics as a way of physically engaging with digital models is convincing. Essentially, a 'haptic-arm' is used to interact with on-screen digital geometry. Movement of the arm provides feedback to the user as digital geometry is manipulated on screen.



Figure 3.8 Haptic force-feedback device in use

Evans et al (ibid) compared the use of analog tools with the haptic force-feedback system. Conclusions indicated limitations in the ability of the system to afford the kind of interaction experienced during the embodiment of design intentions as conventional models, 'The inability of the Freeform/Phantom system to allow the industrial designer to sculpt form through touch and produce acceptable curved surfaces brings into question the relevance of this generation of technology to the profession' (Evans Op cit p506). The study indicated tactile interaction may be better achieved through the use of digital modelling software such as Alias Studio, which might then be rapidly prototyped to provide tactile embodiments, 'by acknowledging the sophistication of state of the art CAD it is necessary to question the need to engage in tactile interaction during the development and definition of form and shift the emphasis to the tactile interpretation of the virtual design outcome' (Evans et al. 2004 p506).

Dorta et al (2008) discusses the development of a hybrid digital tool for use during concept design. His hybrid environment, like the haptic arm, aims to support some of the affordances seen in hand sketching and sketch modelling. The hybrid system (HIS) was used in an experiment to analyse its ability to augment the experiences seen in the designer's use of sketching during conceptual design practice and at the same time afford the benefits of design embodiment through CAD technologies:

The HIS evolved out of a will to augment the advantages of traditional tools. Neither sketch-like rendering made from accurate primitives, nor perfect rapid prototypes share the same advantages of real freehand sketches or rough handmade physical models.

(Dorta et al 2008 p125)

Dorta et al (Op cit) used the notion of ‘design-flow’ (used to describe a designer being in a highly involved reflective activity) to analyse the HIS tool’s effectiveness in support of concept design. The study concluded that the use of the hybrid tool did enhance ideation and so may tell us something of the ways the designer uses ‘flow’ to support concept design (Figure 3.9):

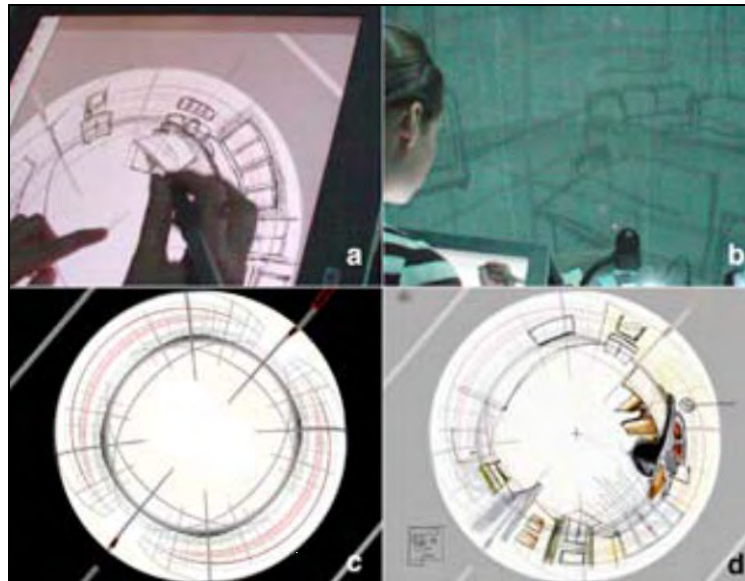


Figure 3.9 Dorta's hybrid ideation space in use.

In recent years graphics tablets have emerged as a means through which the designer may recreate the affordances of hand sketching in a digital environment (Faber 2009). The Wacom Cintiq tablets support illustration software such as Alias SketchBook Pro and Adobe's Photoshop. Figure 3.10 illustrates the Cintiq graphics tablet in use.



Figure 3.10 Wacom Cintiq Graphics tablet in use during design embodiment

In an experiment to understand the different skills required in using digital sketching tools (tablets) compared to analog hand sketching (paper), Faber (ibid) describes a study involving undergraduates undertaking a course entitled 'Digital Drawing'. The study used a questionnaire to identify the student designers' attitudes towards the use of digital sketching. Research findings suggested some differences between the use of analog hand sketching and digital sketching. The ability to undo or erase was seen as a useful function, but also a limitation, 'this was difficult to relate to for students who wanted perfection in their drawings.' Faber (ibid) expressed a concern for the ability of the digital technology to be used to move quickly and fluidly between ideas and that this concern relating to digital undo and editing functions (personal communication, conference question).

A common theme running throughout literature on the use of hybrid technologies is their ability to support the kinds of interaction associated with equivalent analog processes; haptic's ability to support embodied interaction, the graphics tablet's ability to mimic the speed and versatility of hand sketching; Dorta's et al (Op cit) hybrid environment to support heightened reflection-in-action within a digital context. However, the literature indicates the ways the hybrid approach to embodiment may influence design activity in unexpected ways.

Emergent in the literature review of design tool use were relationships between the character of design tools, their use in support of various requirements of the design

process and, to a lesser degree, the designer's influence on tool use. The following section presents activity theory as a framework for investigating tool use during design practice in terms of relationships between the tool-in-hand, the requirements of the design process and the designer's own idiosyncratic approach to practice.

3.5 Activity Theory: An Introduction

Activity theory is concerned with understanding human behaviour through investigation of activity and is a framework for the study of human activity as a process of interaction with the environment (Baber 2003, Kuutti 2001, Engeström, Miettinen et al. 1999). Human activity is informed by a number of co-related principles, namely the practical context within which the activity takes place, the subject or individual performing the activity, the goals or objectives of the activity and the mediating tools used in the activity to achieve the objectives.

Tools mediate a relationship between the tool-user and the objectives of activity within a wider socio-cultural environment (Engeström, Miettinen et al. 1999). Understanding the mediating affordance of the tool within this framework is useful for the investigation of tool use and human activity (Nardi, Op cit). The mediating tool and the ways it is used are inseparable. A greater understanding of pragmatic tool use may only be achieved through the study of tools within a wider, co-relational framework that explores both the tool's influence and that of the tool-user (Baber 2003 p62).

According to Vygotsky, (in Kozulin 2003) the study of human activity is critical in understanding how cognitive processes deal with and relate to activity. Haigger (1967) suggests that the kinds of knowledge involved in the use of tools during activity may be unique, 'The kinds of dealings which are closest to us is as we have shown, not a bare perceptual cognition, but rather that kind of concern which manipulates things and puts them to use; and this has its own kind of 'knowledge'.

Figure 3.11 presents Engestrom et al's (1999) model of activity theory:

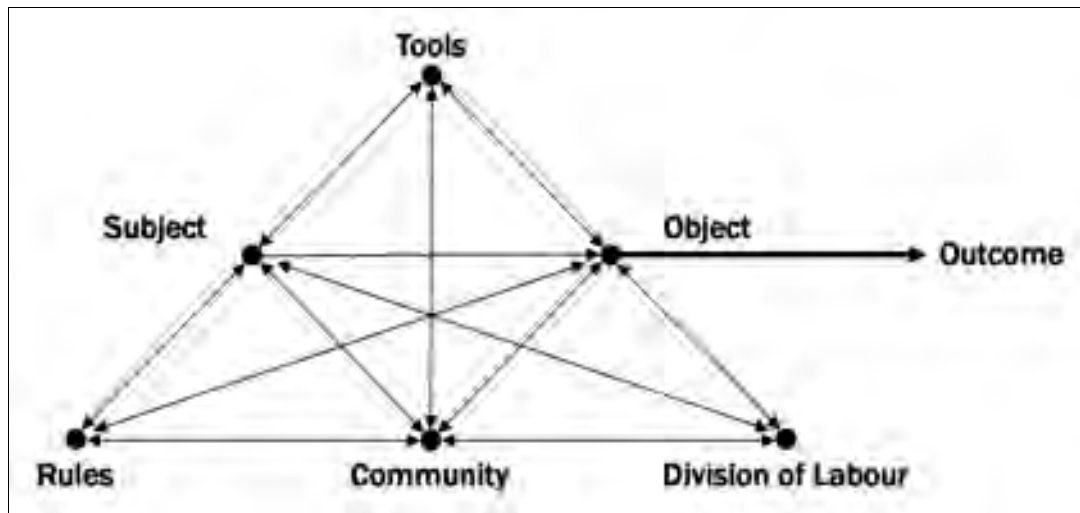


Figure 3.11 Engeström's model of human activity

At the top of the model sits the mediating tool. Located between subject and object, the tool is used to reach the final outcome of activity. The mediating tool is described by Kuutti (2001 p17) as both enabling and limiting; it may be able to support the subject in achieving the objective of activity through, 'historically collected experience and skill 'crystallised to it'. However, at the same time, Kuutti (Op cit) suggests the character of a given tool will also limit the possibilities for mediation.

As mediating tools are different, the way they mediate between the subject and object influences activity. The 'subject' (Engeström & Miettinen et al. 1999) or actor (Baber 2003 p54) is described as the tool-user. As well as the tool's influence, the skills and experience of the subject will influence both the use of the mediating tool and the manner in which the purpose of activity is met.

Moreover, both the tool-user and purpose of use are influenced by cultural factors (Engeström. Miettinen et al. 1999). These factors are expressed within Engeström's (Op cit) model of activity theory as rules, community and division of labour. Rules are described as a set of expectations, values and shared beliefs concerned with a best practice approach to working methods (Baber 2003). Baber (ibid p64) suggests that, 'rules convey the experience of previous users of the tools'. 'Community' relates to the group of people whom both hold these rules, express them and pass them on to new members of the community (Engeström et al 1999). Finally, 'division of labour' refers to the organisation of a community as related to the activity. The critical role of the mediating tool and its relationship to both subject and object within the context of rules,

community and division of labour have parallels to the few existing studies of tool use as part of a wider design activity (Stolterman et al 2008, Stella & Melles 2010).

3.6 Activity Theory and Design

The use of activity theory in the study of design tool use in studio practice is not without precedence. Stella and Melles (ibid), in a small study of the tool-mediated activities of graphic designs, used activity theory as a framework to investigate tool use. They identified its ability to support the description of the activity of design practice from a wider contextual perspective, 'a useful framework for studying the design process, as it can constructively describe the activity structure and development of designers' practices with a contextual perspective' (Stella & Melles 2010 p464).

Stolterman's et al (2008) 'Tool-in-Use' model draws on the principles of activity theory to describe tool use in terms of the purpose of design action, the activity the designer sees as appropriate to achieve that purpose and the designer's choice and use of design tools. Although Stolterman's Tool-in-Use model emphasises designer choice, given perceptions of practice, the co-relational framework has distinct similarities to Engeström's model of activity theory (Engeström, Mietinen et al. 1999).

3.7 Activity Theory and the Designer

Activity theory is discussed here from the cannon of its ability to describe the tool's relationship to the requirements of practice, the influence of the design practitioner and the critical influence of the design tool. To understand the use of a tool one must consider the role of the user (Heidegger 1962, Butler 2004). Engeström et al (1999) refers to the tool user as a critical influence upon the activity at hand. Butler (2004) suggests a tool is only used as a tool insofar as the user has in mind a goal or objective to achieve through the tool's use. In a discussion of what is or may be considered a tool, Butler (Op cit) suggests a tool may only be seen as such through its usefulness to the individual in its pragmatic application, 'it owes its being a tool simply to the fact that it serves a purpose' (Butler Op cit). From this position, design tool use is less a product of the tool itself, but rather achieved through its skilled manipulation in a practical context:

The goodness or badness, again, of a tool depends not upon anything within the tool as regard without relation to the user, but upon the ease or

difficulty experienced by the person using it...thus the same tool may be good for one man and bad for another.

(Butler Op cit)

Heidegger (1962 p96) takes a similar user centred position when describing tools as 'das zeug' (equipment). Heidegger (ibid) describes the tool user's relationship to this equipment as, 'in-order-to'. The tool is a tool only if it is seen as useful in supporting a purpose or goal. A tool 'das zeug' is then used to satisfy a goal or objective. However, tools may also become 'ready-to-hand' in a way that they offer themselves as potentially useful in fulfilling a given task (Heidegger Op cit). This idea has parallels to Norman's (2002) notion of affordances, where tools (a hammer) may be seen to support a given action to achieve a required goal (hammering). The form of the hammer shows itself to be effective in the hammering of nails through an individual's internal modelling of the situation. It also has similarities with Stolterman's et al (2008) 'tool-first' approach to tool use.

The tool user's relationship with a tool will develop over time. As the skilled use of a tool develops, the tool itself will disappear from ones awareness (Baber 2003). The tool is used, with increasing focus on the task and its objectives, 'the object 'disappears' during use and one is aware of the performance of a task' (Baber, ibid p2-3). It is only when the tool unexpectedly fails to perform that attention shifts from task back to tool (Baber, op cit). Baber (Op cit) offers the activity of using chop-sticks as an example. For the more experienced user, attention is focused on activity, while the less experienced user focuses awareness upon the chop-sticks. As one learns and develops skilled tool use, tool interaction changes, 'we rarely focus attention on the use of a tool, particularly when the tool is highly familiar' (Baber Op cit p3). Like Heidegger (Heidegger 1962), Baber (Op cit) discusses an ability to interpret the value of a tool in relation to its support of a purpose.

This ability to interpret relates to the user's skill in retrieving and developing courses of action appropriate to a given situation and the skills to effectively monitor and correct these courses of action during practice (Baber 2003). These abilities are themselves influenced by user background and experience. Generally, as experience of tool use increases, the user becomes more confident and comfortable with the mediating tool in a way that allows the tool to regress from user awareness. This set approach is part of a 'normal' way of doing things in a given culture of working habits, becoming

embedded in practice and having influence upon how tools are used. A key aim of this study was to investigate to what extent design expertise influenced an ability to engage and interpret the value of the design tool in relation to its support of practice. To then consider how this ability may influence approaches to and use of design tools.

Nardi (2001 p7) refers to the inability of the novice practitioner to achieve the kinds of fluid and confident tool use seen in the work of experts. Instead of concentrating on the goal or object of the task, less experienced practitioners are more aware of the tool or mediating object (Engeström, Miettinen et al. 1999). As a result, attention is drawn away from the purpose of activity as it is required to manipulate the tool (Nardi, Op cit). The increasingly skilled use of a tool is a reciprocal relationship between subject designer and purpose where the historical or experimental development of that relationship is distilled within the mediating tool (Kuutti 2001 p17). This may be both empowering and limiting. Empowering because of the skill and expertise tied up in the use of the tool and limiting because interaction between designer and purpose are restricted to the affordance and constraints of the tool in use.

Activity theory is able to facilitate the study of the tool-user to explore their influence on tool use (Butler's 2004). In this way it appears that activity theory and its principle of the subject as critical to tool use but influenced by social cultural factors and contexts of that use, may provide an approach for exploring the designer's role in the use of tools of design embodiment.

A final point to make here is that the designer and purpose of activity (embodiment) are in a co-dependent relationship. This relates to Schon's notion of reflection-in-action. The designer manipulates the embodiment through the use of tools. Reflection on embodiment influences the designer's understanding of the design problem, 'the subject is transforming the object, while the properties of the object penetrate into the subject and transform him or her' (Kuutti 2001 p32).

3.7 Activity Theory and the Industrial Design Process

Activity theory presents the context within which the tool-user works as an influence upon tool use (Baber 2003, Kuutti 2001, Engeström, Miettinen et al. 1999). Design practice is defined by its requirement to progress design intentions towards the final specification of intent prior to manufacture (Cross 2007 p22). As design is progressed sub-goals are achieved in consultation with other stakeholders and design embodiment

is critical to this collaboration. A goal orientated view of tool use is expressed by Baber (2003) who comments that, 'tool' manipulation is directed towards a specific goal or purpose, and the associated activity requires a degree of control and coordination' (Baber, *ibid* p3). The individual's use of a tool is highly influenced by intentionality, i.e. intentions towards a particular outcome. These intentions are both influenced by the skills and background of the tool user and the working context within which the tool is appropriated and used, 'the manner in which a tool is used is influenced by the environment in which it is used' (Baber, *Op cit* p54). Heidegger (1962 p98) describes the influence of intentionality on tool use; the 'in-order-to (Umsicht)' of tools. He considers in-order-to as an important principle of tool use where the user does not concern them self with the use of the tool, but with achieving the objectives of the task; working upon and having an awareness of the objective of the activity through the mediation of the tool (Engeström, Miettinen et al. 1999). This relates to the designer's ability to use tools with an awareness of context of use, or the 'towards-which' of the tool, 'that with which we concern ourselves primarily is the work – that which is to be produced at the time' (Heidegger *Op cit* p99). These two concepts, tool and purpose, are codependent and inform each other within a wider social and cultural context; shared beliefs and understandings as to how activity progresses and which tools may best mediate that activity, what goals and objective can be achieved.

The design community (peers, clients, engineers and other stakeholders) have an influence upon the designer's attitudes towards and use of design tools in that their expectations inform the activity of design. Engestrom et al (1999) describes a 'Division of Labour' as informing an individual's activity. He point to the structures and relationships within the community as they inform activity and tool use. Christiansen (2001 p175) discusses these contextual influences and their effect upon activity and the attitudes and motives of the individual, 'the very conditions given by society carry the motives and goals for the activity together with its tools and methods'.

Research investigating rules, communities and the divisions of labour within industrial design, will contribute to understand of how the requirements of practice (purpose) are themselves influenced by the working contexts within which that practice locates, and how those contexts must influence designer attitudes and working methods, their choice and use of design tools

3.8 Activity Theory and Design Tools

All activity is mediated between subject and object through the use of tools (Engeström, Miettinen et al. 1999, Heidegger 1962). The mediating tool is the means through which the designer moves to manipulate design embodiments to progress, explore and communicate design intentions. Kuutti (2001 p17) terms tools, 'Artifacts of mediation' insofar as they act as a critical bridge, with their own affordance and limitations, between subject (design practitioner) and object (exploration of design problems through embodiment):

An essential feature of these artifacts [tools] is that they have a mediating role. Relations between elements of an activity are not direct but mediated...the object is seen and manipulated not 'as such' but within the limitations set by the instrument'

(Kuutti 2001 p31)

Kuutti (Op cit) refers to the influencing character of a given tool in his discussion of the mediating object as it informs practice through the kinds of mediation it supports. In design activity, the relationship between practitioner and object is informed by the kinds of mediation supported by any given tool, as the character of the tool-in-hand influences the kinds of activity undertaken (Kuutti, Op cit). An example of the influence tool characteristics have is seen in Bellamy's (2001) study investigating the impact of introducing new technologies within education. The emergence of digital tools influenced the kinds of activities performed in practice. The introduction of different mediating tools had a ripple effect that influenced both the activities used in practice and attitudes towards those activities. The community's attitudes influenced the ways the technology was appropriated and used:

The introduction of new artifacts [tools] into an activity affects, from the perspective of the activity, the kinds of processes, social and individual, that develop. Similarly, the existing social processes of the community in which the activity takes place...will affect how a new artifact will be used.

(Bellamy, ibid p123)

As the tool-user continues to develop skills and understanding of the tool's use in supporting objectives, the tool and user come together (Christiansen 2001 p175). A

working through the tool is achieved as awareness shifts away from tool to purpose of use. However, as a different or new tool is used, so this working through is interrupted and the activity must necessarily change (ibid). This skilled use of tools is seen as inseparable from the practitioner's perception of the tool and its effectiveness in supporting the purpose of use. Heidegger (Op cit) notion of 'towards-which', 'Not only are the skills obtained through the incorporation of the tools inseparable from the tools themselves, the tools become an integrated part of the prism.' (Christiansen, Op cit)

The character of the tool used to mediate between the individual user and the object of use has implications for the approach taken to a given activity and how that activity is performed and understood:

The artifacts (tools) are not merely improving the person's ability to perform an existing action, but are rather modifying the way the action is approached, conceived and performs.

(Baber 2003: 106)

The user's reaction to a tool will also influence its use. Engestrom (Engeström, Miettinen et al. 1999) describes this as 'Praxis', whereby working methods change to suit the perceived affordance of the given tool and so, by implication, different tools provoke different working methods.

Like all tools, the design tool has an influence upon the ways that the practitioner works in order to achieve the design purpose. This is due both to the implicit affordances and limitations of the tool, and the practitioner's perceptions of a given tool, its 'readiness-at-hand' (Heidegger 1962 p98). This perception is influenced by the individual's goal orientated use of the tool, its 'in-order-to' (ibid).

Activity theory is a clarifying and descriptive tool (Nardi 2001 p7). However, industrial design practice is unusual in its concern with the specification and communication of intentions towards a final outcome. The outcome of activity is not the end, but a set of specifications for further development and final manufacture. Descriptions of activity theory and the use of tools are concerned with activity as it is used to achieve objectives and outcomes that emerge from activity. The use of a hammer in achieving the objective of hammering a nail into a wall with the goal of having the nail in such a way as it then supports the hanging of a picture. For industrial design practice a final

goal outcome is not achieved through the activity of embodiment, but often by remote manufacture. Moreover the goal outcome is unknown because of the ill-defined design problem (Cross 2008 p13-14). The various requirements of studio practice mean that these end 'goals' may not be known in the same way as one knows what one would like to do when using a hammer. Solutions and goals are unknown but emerge from exploration of solution ideas through design embodiment.

Within these limitations, activity theory provides a framework of codependent influences that exist in the use of design tools: the user's own perception of the tool, the tool itself and the influence of the contexts within which the tool is used, working cultures, methods and stakeholder influences. The use of activity theory as a means to describe design tools and their use in practice reflects Kuutti's (2001) position of the theory having universal value across various activities:

Broadly defined, activity theory is a philosophical and cross-disciplinary framework for studying different forms of human practices as development processes, with both individual and social levels interlinked at the same time.

Kuutti (2001 p25)

3.9 Modelling Design Activity and Tool Use

In this section activity theory has been presented as a means through which human activity, including design activity, may be studied. Figure 3.12 presents an adapted version of Engestrom's model of activity theory:

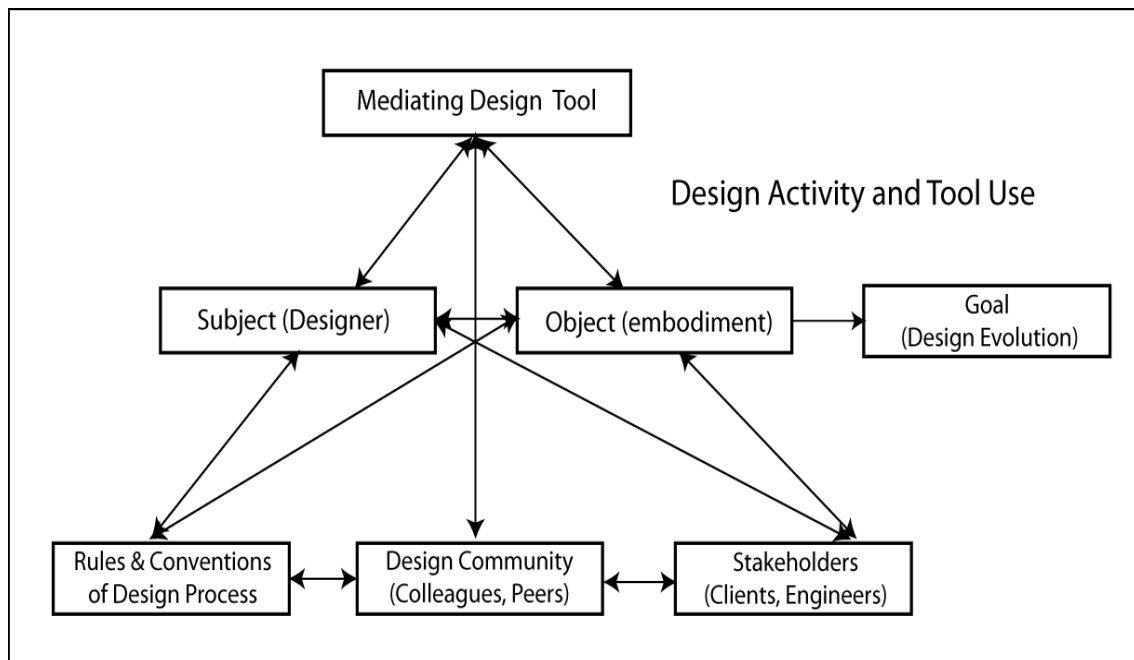


Figure 3.12 Model of industrial design activity and tool use based on the Engeström's model

The model is a relational system of influences that together inform tool use within industrial design practice. A description of each of the principles illustrated in the model is presented below.

Mediating Design Tool

This is the tool through which the design practitioner embodies design intentions during studio practice. Commonly used design tools include design sketching, 3D CAD, rapid prototyping, physical modelling of varying fidelity, graphic illustration (hand-drawn, digital and hybrid) and CAD engineering drawing. The Mediating Design Tool is a bridge between the subject (designer) and object (embodiment). It is used by the designer to externalise and reflect upon design intentions. The design tool is more than the media used in the embodiment of intent (e.g. the pencil, graphics software, rapid prototyping machine) but a process through which design embodiment is achieved. The character of the tool-in-hand has an influence upon the kinds of embodiments made, and thereby influences design activity.

Subject (Designer)

The Subject (Designer) represents the designer's influence as they use design tools to embody design intentions during studio practice. Through their habits, working methods, background, levels of experience and skill in tool use, they influence the way

the design tool is manipulated to embody design intent. The Subject (Designer) is also influenced by the wider context within which studio practice locates. These wider contexts represent the requirements of a given stage in design practice, established working practices and the influence of the hierarchical responsibilities within the new product development process that includes various stakeholders and their expectations.

Object (embodiment)

Object (embodiment) represents the object of purposeful tool mediated design activity. This is the process of design embodiment made by the design practitioner through the use of mediating design tools. These embodiments may take the form of sketches, drawings, physical models and prototypes. Mediating Tool and Object Embodiment are co-dependent. The nature of the design embodiment will be influenced by the design tool used. Design embodiment is also influenced by the subject practitioner their skills and experience. Practice is also influenced by a wider context; responsibilities and requirements within the design process, other practitioners and design commentators and the requirements and expectations of stakeholders. Notably, these relationships are reciprocal. As well as the wider context informing tool use in studio practice, emergent design tools, renaissance practitioners and significant design research outcomes can permeate these wider contexts.

Goal (design evolution)

The design outcome represents the transformation of object embodiments to design outcomes as solution ideas. These outcomes of design activity may take a variety of forms to satisfy different purposes as studio practice progresses from concept, through development and into detail design. These may include an exploration of concept ideas; explanation of intentions to stakeholders; the specification and prescription of design intent for engineering and manufacture and the description of design details.

Rules & Conventions of Design Process

Rules & Conventions of Design Process refers to the shared beliefs or established patterns of working partly or wholly shared by the design community. Rules may relate to the ways the design tool has been employed in the past or the systems and processes in place that act as a framework to guide the progress of design. Emergent tools and innovative use in design embodiment may challenge these established norms and conventions may change over time.

Design Community (Colleagues and peers)

The design community is made up of designers and related professionals, educators, design commentators and theorists. The community holds both the rules and finds ways of passing them on to the next generation. In this way, they have influence upon the ways design tools are accepted and used to support studio practice.

Stakeholders (Clients and Engineers)

This refers to the various individuals, groups and organisations that inform industrial design practice. These may include higher management and directors; clients and funders, engineers and manufacturing. The kinds of design embodiments made, and the ways in which the designer manipulates the design tool to embody intent, are informed by an understanding of the perceived requirements of these various stakeholders, how they relate to different stages in studio practice and how design intent may be best communicated to them.

There exists a substantive body of work relating to the influence the mediating tool upon design activity (Goldschmidt 1997, Bilda & Demirkan 2003a, Goel 1995, Dorta, et al. 2008, Pipes 2007, Jonson 2005, Menezes & Lawson 2006). Some of these are descriptive in that they discuss the use of a given tool at a stage in practice, with little analysis of the relationships indicated in the Model of Design Activity and Tool Use (Figure 3.12). Others have investigated the critical influence of the design tool as it relates to the kinds of embodiments made and how this then influences studio practice (Goel 1995 p193). However, these studies are often orientated towards the mediating tool's influence on practice through the relationship between mediating tool and design embodiment.

Exceptions were found in the work of Gunther and Ehrlenspiel and Pan and Kuo (Günther & Ehrlenspiel 1999, Pan & Kuo et al. 2010). Gunther's and Ehrlenspiel's investigation of design practitioners with no formal education and those with university degrees offers insight into the ways that design expertise critically influences studio practice. Differences between the sample groups included length of time given over to conceptual development and clarification of the design problem at the start of the design task. Percell & Gero (1999) investigated the notion of design fixation, points to the influence of design discipline as affecting a tendency to fixate upon a given design intention, with the engineering designers tending to show a greater tendency than

industrial design practitioners. A study by Manolya et al (1998) investigated the design activity of a single novice and single expert designer. Findings indicated differences in approaches to design practice that relate to a cognitive activity and productivity, with the expert's being three times more productive compared to the novices. And finally, Stolterman's et al (2008) Tool-in-Use model described the skilled use of design tools and the designer's own perceptions of tool effectiveness as influences upon choice and use of tools during practice. The research undertaken here locates within and expands upon this discreet body of work.

The use of activity theory is not to prescribe a definitive method of investigation, but rather is employed to underpin the exploration of attitudes towards design tool use (Chapters 6, 7 and 8). It is used as one method of mapping principles of design activity and in doing, was used as leverage in research analysing tool use during industrial design practice (Chapters 6 to 8).

Chapter Summary

The Chapter reviewed design tools within the context of studio practice. This review considered the design tool's role in terms of the various requirements of design activity; from iterative and divergent conceptual design through to design specification prior to manufacture. This was followed by a review of the notion of design as a reflective activity and the critical role design tools of embodiment play within reflection-in-action. A review of industrial design tools explored ways in which they are used to support studio practice. Analog, digital and hybrid tools were considered in terms of their character.

Activity theory was introduced, reviewed and discussed as a framework for understanding tool use during design practice. A model of activity theory was presented and the principles within the model discussed in terms of their suitability in offering a more holistic description of design tool use during practice. A revised version of the model of activity theory was presented along with a description of how the principles within the model relate to design activity (Model of Design Activity and Tool Use). The Chapter ended by suggesting a new approach, based upon activity theory, for analysing design tools, their relationship to studio practice and the designer's own influence on tool use through their idiosyncratic approach to design tools.

Chapter 4: Taxonomy of Design Tools

Introduction

The following chapter is a review, identification and classification of commonly used design tools. These tools are categorised within a taxonomy based upon their use within design practice to support concept, development and detail design. The taxonomy, resulting from a literature review of pragmatic tool use, was seen as a first step in providing an overview of tool use in studio practice, rather than a prescriptive or definitive classification of tools. The taxonomy is used as a starting-point to analyse relationships between various design tools and their use by the practitioner in support of design embodiment for different purpose; from iterative, concept design through to more prescriptive detail design. The aim of the taxonomy was to develop understanding of relationships between the different requirements of the design process and the place of use of various tools.

4.1 Existing Design Tool Taxonomies

Simon (1996 p133) describes the importance of classification as a first step in understanding the reasons for any phenomena when considering the kinds of representations used to support design practice, 'An early step towards understanding any set of phenomena is to learn what kinds of things there are in any set – to develop a taxonomy. This step has not yet been taken with respect to representations.' However, a number of existing attempts to define and categorise design tools were identified. A common thread within all was the aim of classification to better understand the role tools play in support of studio practice.

4.1.2 Pei et al's Taxonomy

Pei et al's (2008) taxonomy categorises design representations in terms of their ability to support various kinds of design activity, from the conceptual sketch to beta prototypes used in testing and validation prior to manufacture. Pei et al's (ibid) definition of design 'representation' has commonality with the term 'embodiment' as it is used here (the practitioner's use of design embodiments of various kinds to understand and progress the design problem towards final specification). However Pei et al's (Op cit) research explored issues in communication between industrial designers and engineering design practitioners and how representations are referred to and used to communicate design intent between the two groups. Based on a literature review of representations employed by industrial and engineering designers, Pei et al (Op cit) presents a taxonomy which classifies design representations into four distinct categories: sketches, drawings, models and prototypes (Figure 4.1). These representations are further categorised under second and third tiers to suggest the ways that they are used to communicate and development design proposals. A third tier then sub-divides these terms as they are used by the two groups. For example, concept drawings (industrial design) compared to general arrangement drawings (engineering design); appearance models (industrial design); functional concept models (engineering design); appearance prototypes (industrial); and experimental prototypes (engineering). The taxonomy does not classify sketch representations in this way, instead categorising the sketch in terms of the ways that they are used in practice: i.e. personal, shared, persuasive and handover sketches. These are then divided again to suggest the kinds of sketch representations made under each of these four headings (Figure 4.1):

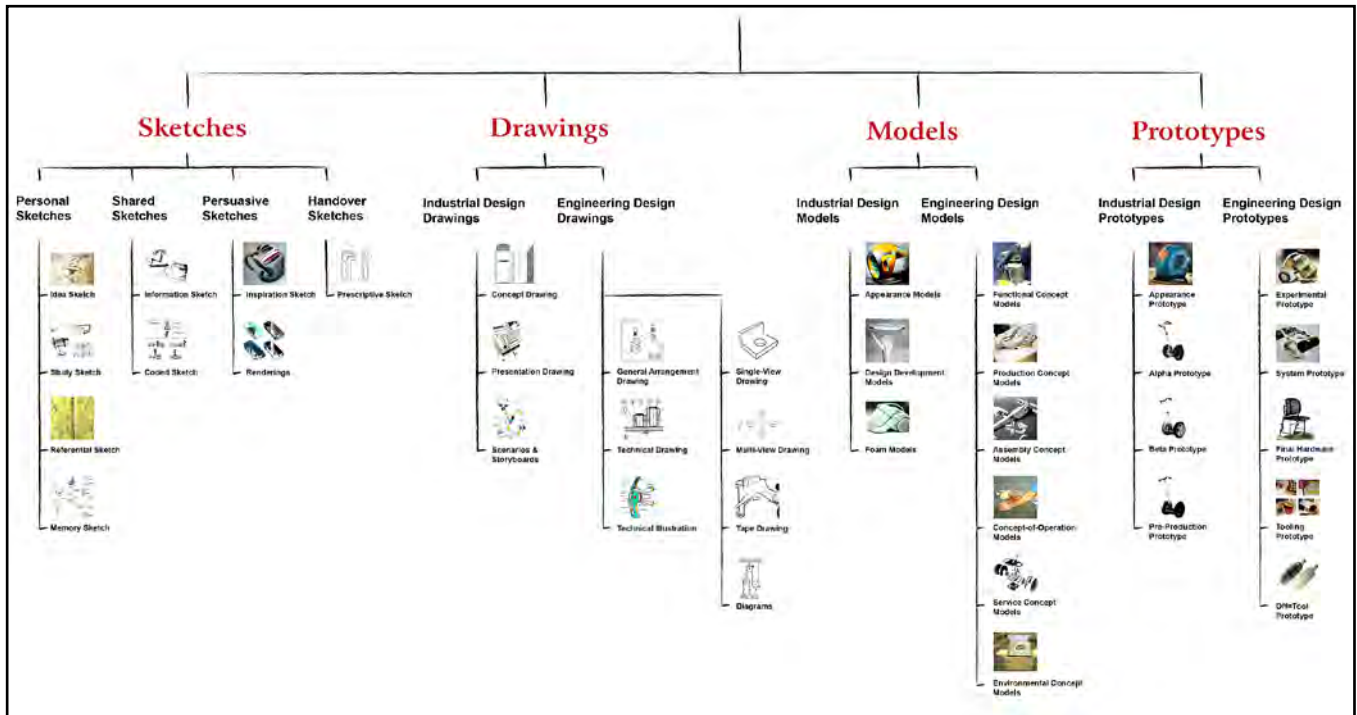


Figure 4.1 Pei et al's taxonomy of design representations

Many of the terms of reference used in Pei et al's taxonomy are from pre-existing literature on tools and tool use (Cross 2007, Bilda & Demirkan 2003a, Goel 1995, Lawson 2006, Schon 1983, Cross & Christiaans et al. 1996, Tovey & Porter et al. 2003, Römer & Pache et al. 2001). Although the taxonomy was used in an investigation aimed at understanding the different ways in which industrial and engineering design practitioners communicate, it also indicates the relationship between design representation and the various requirements of studio practice; from an open, iterative conceptual design sketch to the specification of intent through detailed prototyping.

4.1.3 Stolterman et al's Taxonomy

Stolterman's et al (2008) study describes a 'Tool-in-Use' model of design practice. Within this model, the designer selects and uses the tool perceived to be of most suited for the purpose of the design activity at a given stage in practice. Stolterman et al (ibid) takes a more encompassing approach to suggest that any object or system used to support a purposeful design activity may be considered a design tool, departing from this study's description of tools as those supporting external embodiment of intent.

Stolterman's et al (2008) system of tool classification consisted of two tables. In the first, designers were surveyed on the kinds of tools used during their studio practice. These

were then categorised under the headings of physical tools, software tools, theoretical tools and others (Figure 4.2):

Physical tools	Software tools	Theoretical tools and others	.. and others
Pen paper pencil	Acrobat reader	Mind mapping	Verbal
Whiteboard	Website	Ethnography	Face to face
Markers	Photoshop	Questionnaires	Mouth
Eraser	PowerPoint	Film theory	Mind
Big pad of paper	fireworks	Personal experience	Hand gestures
Sheets of printer paper	Axure RP	Facts	Thoughts
Color marker	Flash	Surfing for ideas	Prior knowledge
Post it notes	Secondlife	Lit review	Eyes
Tangible stuff	Illustrator	Stories	Ears
Audio recorder	Indesign	Books	teammates
Video recorder	Digital software	Magazines	
Digital camera	Wireframes	Carrols method of scenarios	
Foam core	Tec smith morae	Hazbolts method of affinity diagramming	
Pair of scissors	Camtasia	Heuristics from	
	CSS HTML	Nielson/Norman	
	MS excel	Activity theory	
	MS word	Ideas of external cognition	
	Visio	Contextual enquiry	
	Survey	Usability guidelines	
	monkey.com	(frameworks including	
	word press	aesthetics, functionality,	
	software tools	mediation,	
	online repositories	breakdown,	
	Google images	Symbolism, usefulness)	
	Blogs		
	random word generator		

Figure 4.2 Stolterman's classification of design tools mentioned by subject designers

A second table describes the types of activities mentioned when using tools (Figure 4.3):

Sketching Collaborative Sketching (whiteboarding) Critiquing Prototyping Interviewing Observing Photographing Storyboarding Leading Focus Groups Usability Testing	Brainstorming Interviewing in Context (contextual inquiry) Looking at other examples Creating Scenarios / Personas Sitemapping Wireframing Infinity Diagramming	Writing Creating Presentation Presenting Creating/Distributing/Analyzing Cultural Probes Sense Mapping Bodystorming Research Creating/Distributing/Analyzing Surveys Performing A Literature Review Journaling Cutting Listening (to think aloud)	Meeting and working with colleagues Teaching Blogging Watching YouTube Analyzing business impact Analyzing future effects of design Programming Drawing/Coloring	Getting user feedback Performing expert walkthrough
---	--	--	--	---

Figure 4.3 Stolterman's table of design activities mentioned by subject designers

Stolterman's aim was not to prescribe or explain best practice approaches to tool use, but to illustrate the rich relationships that exist to inform tool use in practice (Op cit). The classification is an illustration of the variety of tools used in the many requirements of practice rather than an indication of which tools may be used and it what ways. Stolterman's et al (Op cit) study, although taking a broader approach to the use of the term 'design tool', has significance in that the identification of a variety of tools suggests a rich complexity in tool use.

4.1.4 Pipes' Classification of Design Drawings

Pipes (Pipes 2007) defines industrial design tools in terms of their practical use within industrial design activity and places them according to where they are used to support practice, 'The purpose of this chapter is to categorise these products, identifying them according to their most appropriate place in the design processes, (Pipes 2007 p11). Pipes' describes the 'design tool' as the mediator of reflection upon the process and outcome of embodied intentions in visual and/or physical form, 'It is a means of externalizing and analysing thoughts and simplifying multi-faceted problems to make them more understandable' (Pipes 2007 p15).

Pipes (ibid) classifies design tools through a series of book chapters which describe tools as they are used at a given stage in practice: Concept Sketching, Presentation Drawings and Visuals, General Arrangement Drawing to Production and finally Technical Illustration. A chapter relating to concept design identifies sketching as the primary tool through which practitioners embody design ideas. Pipes (Pipes 2007) goes on to discuss client expectations as influencing the kinds of embodiment made.

Sketches are then categorisation in terms of their purpose of use in practice, 'a means of crystallizing a vague inkling that may or may not be worth pursuing' (Op cit p113). The discussion then moves to position other tools, such as 3D CAD modelling and hybrid illustration, against their ability to satisfy the requirements of conceptual design practice. Finally, design embodiment during pre-production is described as a digital process wherein the primary concern is the final and exacting specification of design intent prior to manufacture. In Pipes (Op cit) text, the system of classification is not explicit, but rather a discussion of tools in terms of their relationship to the convergent nature of the design process.

There is little indication of the ways in which physical embodiments may be used to support practice: rapid prototyping and model making. Although Pipes (Op cit) does engage with the requirements of practice as context of tool use, the discussion employs anecdotes from design practitioners as supporting evidence.

4.1.5 Olofsson & Sjolen's Classification of Sketching

Olofsson and Sjolen (2006) classify various kinds of design sketching in terms of their ability to satisfy the requirements of practice. Investigative and explorative sketches are described as those used during conceptual design to understand the design problem through the generation and exploration of solution ideas. A number of visual examples are provided along with annotation explaining the intentions behind the kinds of embodiments made and tools used, 'The designer found one line art sketch of the robot particularly interesting, and used Photoshop to quickly explore further shape and colour possibilities' (ibid p46, Figure 4.4):

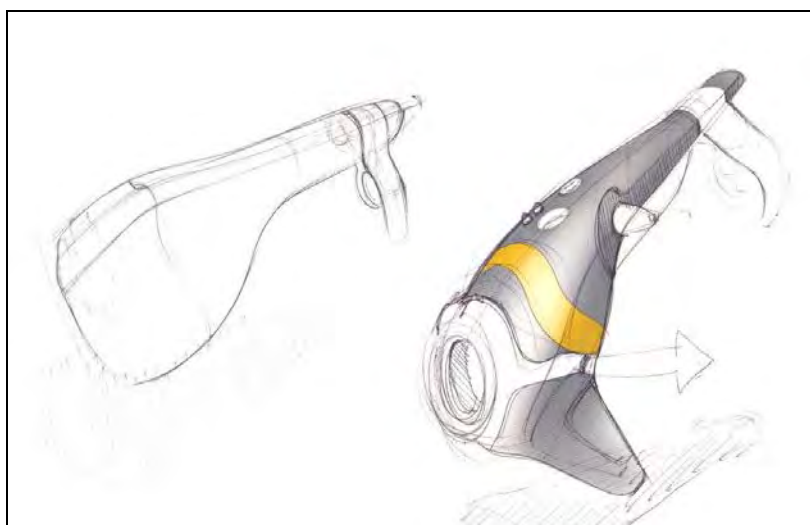


Figure 4.4 Hybrid sketching and digital graphics tools

Olofsson and Sjolen (ibid p46-71) go on to describe explanatory sketches, created to explain function and form and as a means to communicate design intent to others in order to promote collaborative discussion. Example illustrations are provided with annotations reflecting upon the purpose of embodiment: ‘this sketch shows a suitcase from several different angles in order to describe its functions and features (felt-tip pen, marker, Photoshop, Figure 4.5):

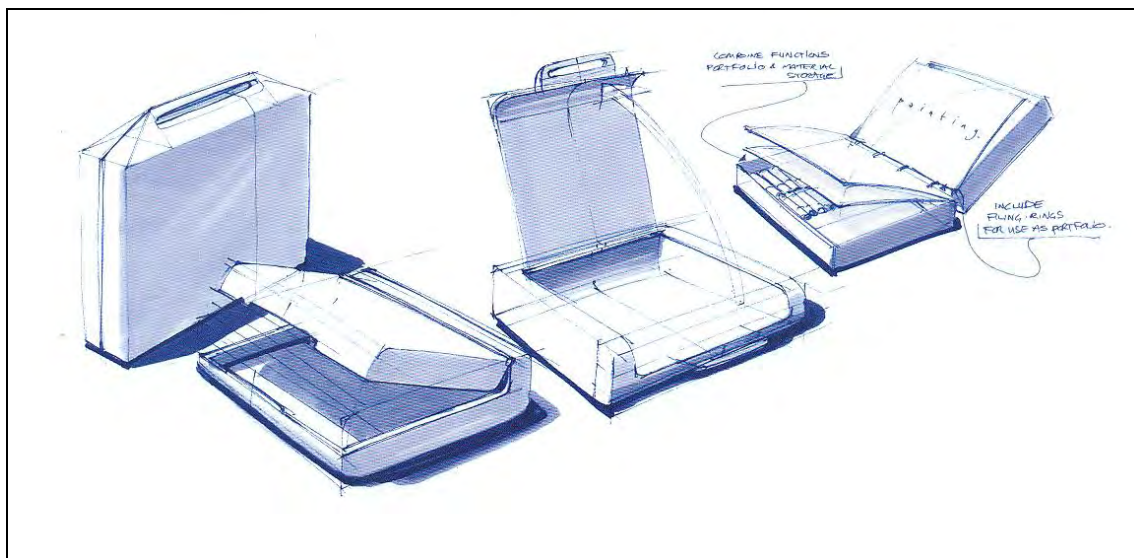


Figure 4.5 Sketches used to communicate intentions towards functionality

A third category of sketch is presented as the persuasive sketch, communicating the feeling or emotion of the proposed design solution. Olofsson and Sjolen (2006 p5) point out that their classification of sketch types is not definitive and that various sketches will be used at different stages in practice. Moreover, that the role of sketching is informed by the various requirements of practice. Olofsson and Sjolen’s (Op cit) discussion indicates a relationship between the designer’s use of the tool and the way it may be manipulated to embody design intent in various ways to support a dynamic studio practice.

4.1.6 Slack’s Description of Tools

Slack (2006), drawing on the notion of reflection-in-action (Schon 1983), suggests a definition of the design tool:

Tools for the development of design rather than the production of the end item vary from the paintbrush to the computer, yet they all share a common factor – they are the means by which a designer defines an idea internally and communicates these findings to others.

(Slack 2006 p88)

Slack, (ibid) like Stolterman et al (2008), indicates the dual purpose of the design tool in its use in support of personal design cognition and in communication of design intent to others. Slack (Op cit p88) makes reference to the funnelling effect of the design process where conceptual design moves to development and on to detail design and production. With the paralleled use of various design tools Slack states that, 'Tools can be objects that fuel the generation and definition of the original idea, through to the hardware that maps its shape and details its production'.

Like Stolterman et al (2008), Slack's (2006 p88) use of the term tool encompasses a wide range of activities to include, 'collections of materials or finishes, objects lost or found, libraries of magazines and books, scrapbooks and storyboards, cameras, computers, software programmes, printers, a ruler, a scalpel, a notebook, a pencil...'. However, she does not discuss the ways that these tools may be employed; the influences upon their use; how this might relate to tool character; practitioner background or the wider contexts within which tool use locates.

4.2 The Taxonomy of Design Tools

A taxonomy of design tools is presented below in Figure 4.6. The taxonomy was not intended as a prescriptive or definitive classification of tools, but instead provided an opportunity to map-out relationships between the mediating design tool and its practical application during design activity (Chapter 3, Model of Design Activity and Tool Use). Design tools were classified within the taxonomy as tools of concept, development or detail design practice. A decision as to which of the three categories each tool would be placed was made in terms of where the literature indicated that the tools were used most often. The taxonomy classified 10 design tools. Of course, some or all tools may be used at various stages in design practice. The taxonomy is not a holistic approach to classification of all tools, but provides a starting point for understanding the phenomenon of tool use in practice (Simon 1996). The simplification of practice as three iterative stages (concept, development and detail design) and classification of

tools according to these stages was a means to start to consider how practice and tool use relate. The 10 design tools help to indicate the variety of tools used and the ways the various tools, with different affording characteristics, are employed to support the different requirements of the design process (concept, development and detail design, Figure 4.6):

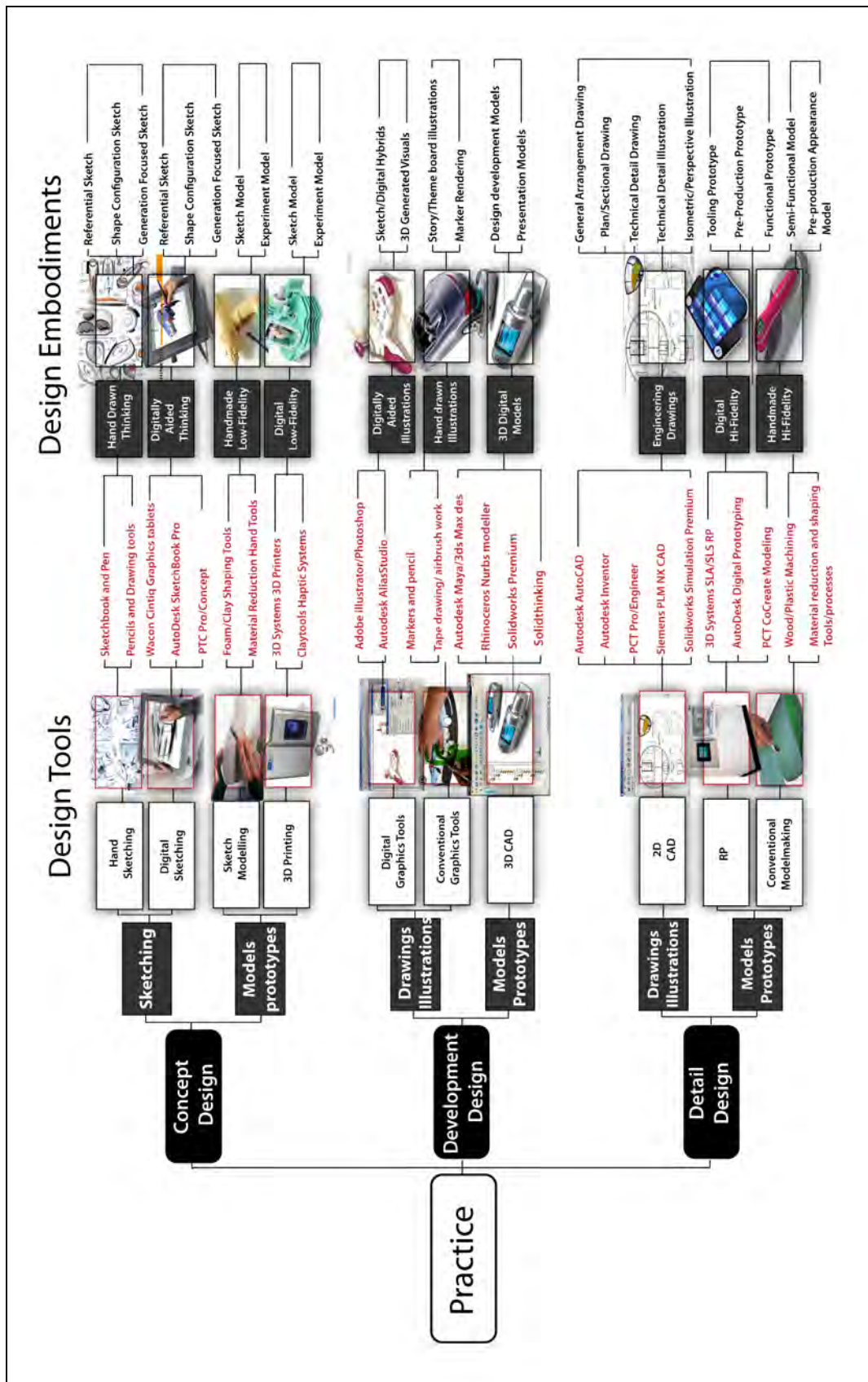


Figure 4.6 Taxonomy of 10 design tools within 3 stage model of design process

Tools within the taxonomy were sub-divided into 'Drawings & Illustrations', 'Models & Prototypes' and 'Sketching' (Figure 4.6). These divisions highlighted a distinction between tools that mediate design intent as 2D images and those as physical 3D artifacts, with the exception of 3D CAD Modelling which was classified under 'Models & Prototypes' to reflect its mediation in 3D, albeit within the digital environment. The term 'Sketching' also replaced 'Drawings & Illustrations' categorised within 'Concept Design' (Figure 4.6).

The following sections provide a detailed breakdown of the taxonomy's component parts. This is followed by an account of each of the 10 design tools categorised within the taxonomy.

4.2.1 3 Stages of Design Practice

Literature describes industrial design practice as progressing from an open conceptual design stage through development and into detail design (Chapter 3). The taxonomy identified the tools most often used to support design in terms of these three stages in studio practice. Figure 4.7 shows a macro the three stages as they are presented in the taxonomy:

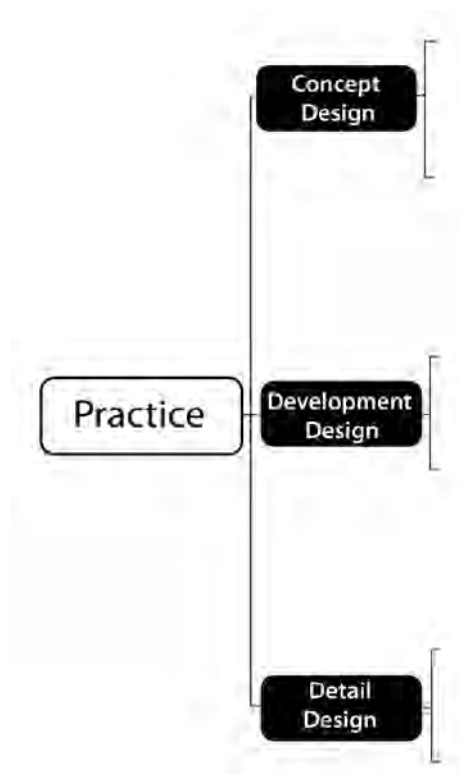


Figure 4.7 Section of taxonomy showing 3 stages in design practice: concept, development and detail design

4.2.2 Division around 3 Stages in Design Practice

Figure 4.8 shows the sub-division of the 3 stages in practice described above. These sub-divisions were termed: Drawings & Illustrations, Models & Prototypes and a single sub-division termed Sketching:

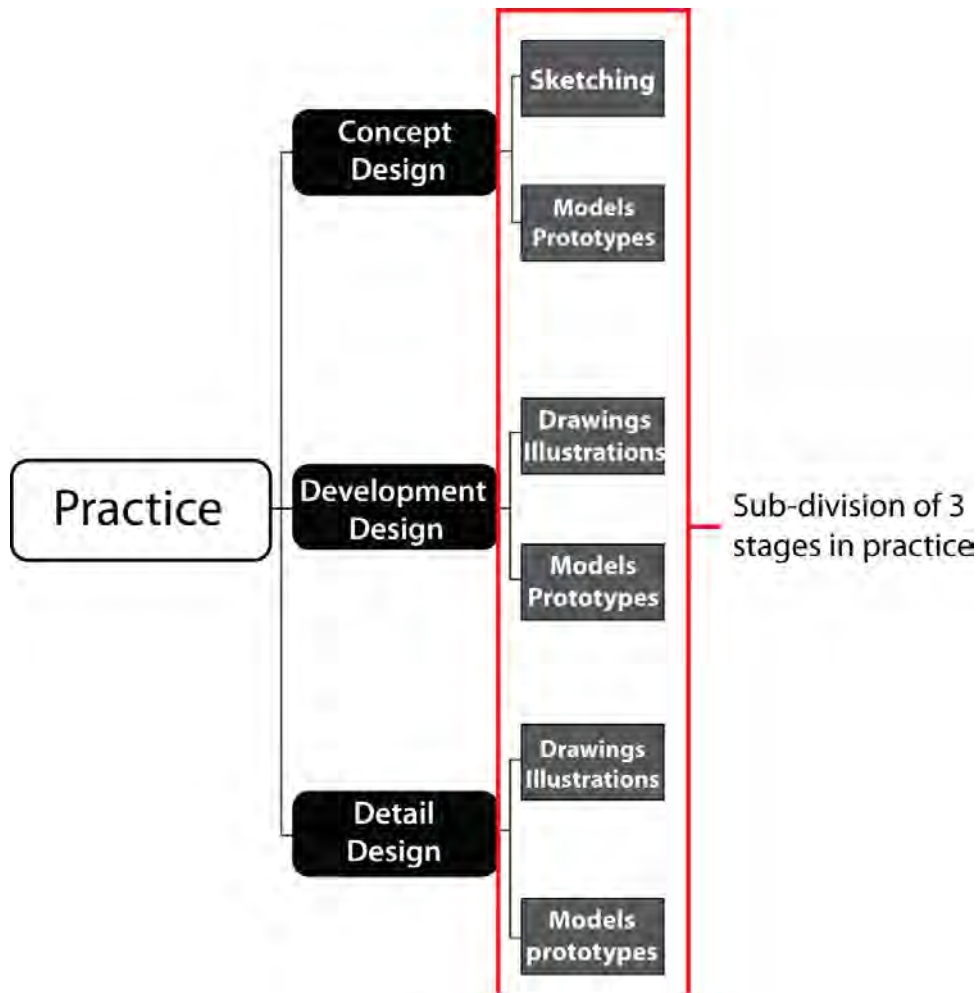


Figure 4.8 Subdivision of concept, development and detail design

There is significant difference in the character of design ideas embodied as drawings and illustrations and those taking on a physical form as models and prototypes (Evans 2002). However, the lines between the two have become increasingly blurred with the use of tools such as 3D CAD, rapid prototyping and the emergence of new human-computer-interaction technology such as haptic devices (Dorish 2001). The taxonomy makes a distinction between design tools employed to embody design intent through the visual and physical embodiment (Dorish 2001).

‘Sketching’ was also distinguished from ‘Drawings & Illustrations’ to indicate the particular use of the term. (Bilda & Demirkan 2003, Goldschmidt 1992, Goldschmidt 1994, Jonson 2005). Sketching was described as a tool, often but not exclusively, used during a divergent conceptual stage in the process. Whereas drawing was often referred to as more specific: Engineering drawings to support manufacture; colour graphic illustrations to develop and communicate design intent.

4.2.3 Classification of 10 Design Tools

The next section of the taxonomy (Figure 4.9) classifies 10 Design Tools. These 10 tools are classified by the stage in practice literature suggested they are often used. Each tool is labelled to reflect the terms used to describe the particular tool. An image showing an example of the tool is placed to the right. To the right of each image a list, in red, provides examples of the various types of each tool:

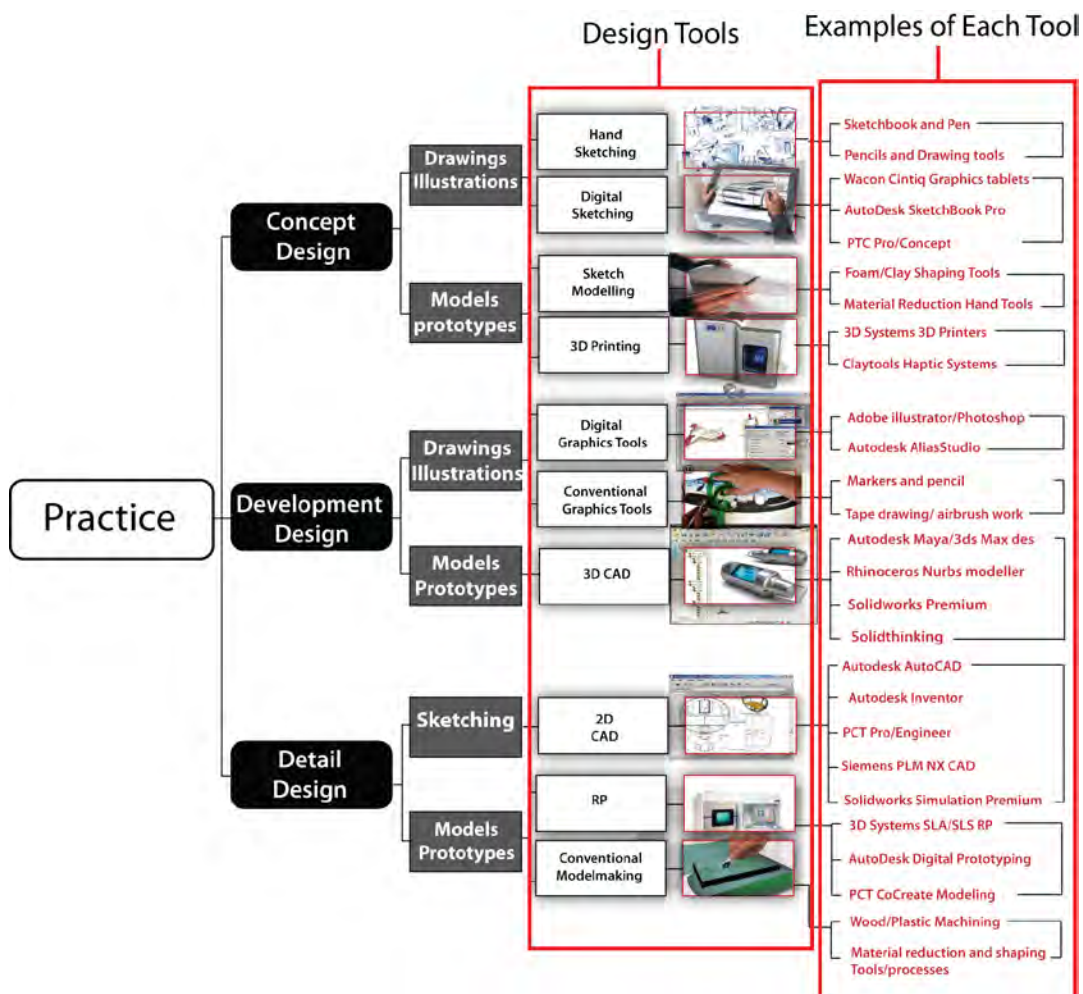


Figure 4.9 Classification of tools within taxonomy and specific examples of tool types

4.2.4 Classification of 10 Design Embodiments

The taxonomy also shows the different kinds of embodiment constructed through the use of the 10 design tools (Figure 4.10). These are examples of the outcomes of design embodiment through the mediating use of the design tool i.e. the outcome of the purposeful application of the design tool during embodiment. These embodiments are the manifestation of intent that is then used for the purpose of communication of intentions to others or oneself as reflection-in-action. As the practitioner uses design tools in a process of design embodiment, their understanding of how the embodied outcome will be employed, must influence the kinds of tools used and the way they may be manipulated to achieve purpose. In this way, the designer, the mediating tool and the wider context of its use are critically related (Model of Design Activity and Tool Use, Chapter 3). Figure 4.10 illustrates the generic terms used to describe the embodied outcomes resulting from the use of the 10 design tools along with example images:

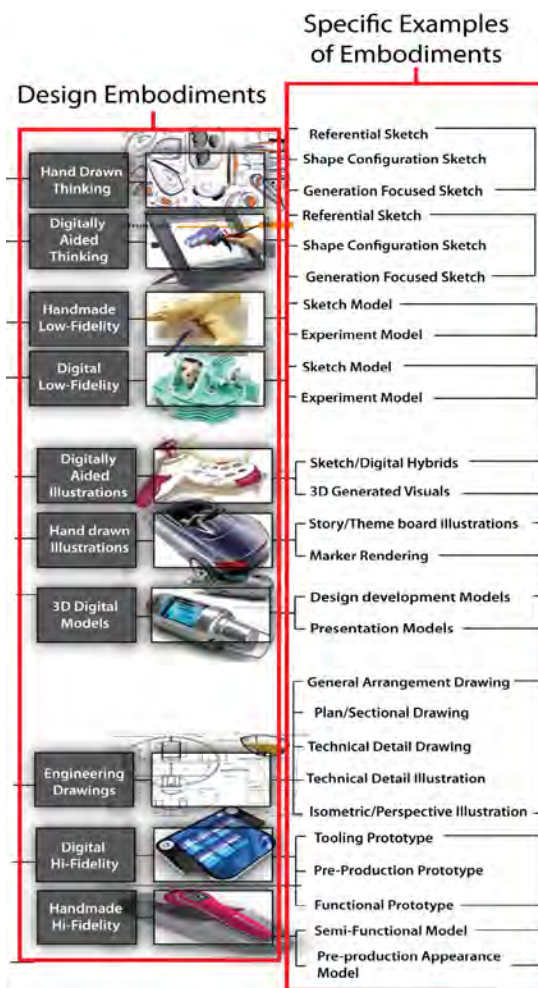


Figure 4.10 Design embodiments made through the use of tools

The 10 tools classified within the taxonomy were identified as a result of a review of literature on design tool use in practice. Each of the 10 tools, the terms used to describe them, and the kinds of embodiments made through their use, are discussed below with reference to the source literature.

4.3 Tools Used During Concept Design

The literature consistently referred to four tools as used in support of an early conceptual stage in practice: hand sketching, digital sketching, sketch modelling and 3D printing. These four tools were categorised within 'Concept Design' and further classified under 'Sketching' and 'Models & Prototypes' (Figure 4.11).

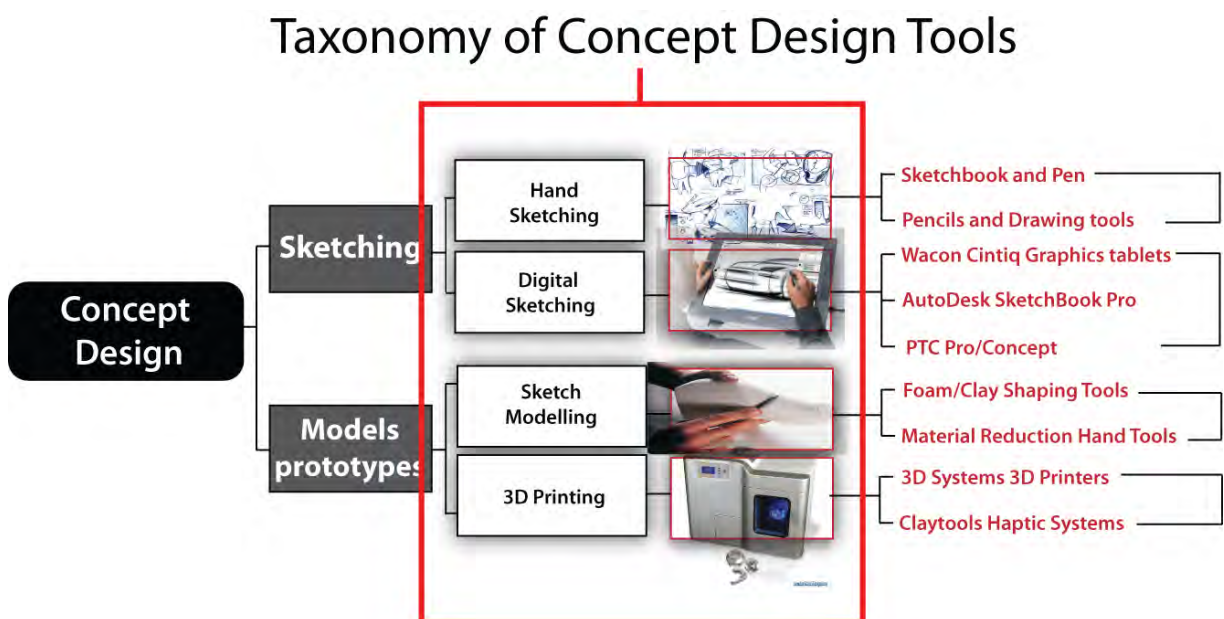


Figure 4.11 Classification of concept design tools within the taxonomy

4.3.1 Hand Sketching

Pipes (2007 p88) describes the effectiveness of the sketch as, 'a means of crystallizing a vague inkling that may or may not be worth pursuing'. Hand sketching also serves as an additional external memory to store ideas, with ideas then being manipulated and developed to explore and progress design (Lawson 2004). The medium used by the designer to construct the sketch is less important: 'I do not have a favourite pen or a pencil...Ballpoints on napkins work just as well as mechanical pencils on Mylar' (Pipes 2007 p71). Sketching is important for the less-structured nature of concept design in that it facilitates the fluid generation of ideas at the front end of practice, 'The conceptual thinking process of the designer seems to depend on the development of ideas through their external expression in sketches' (Cross 2008 p25).

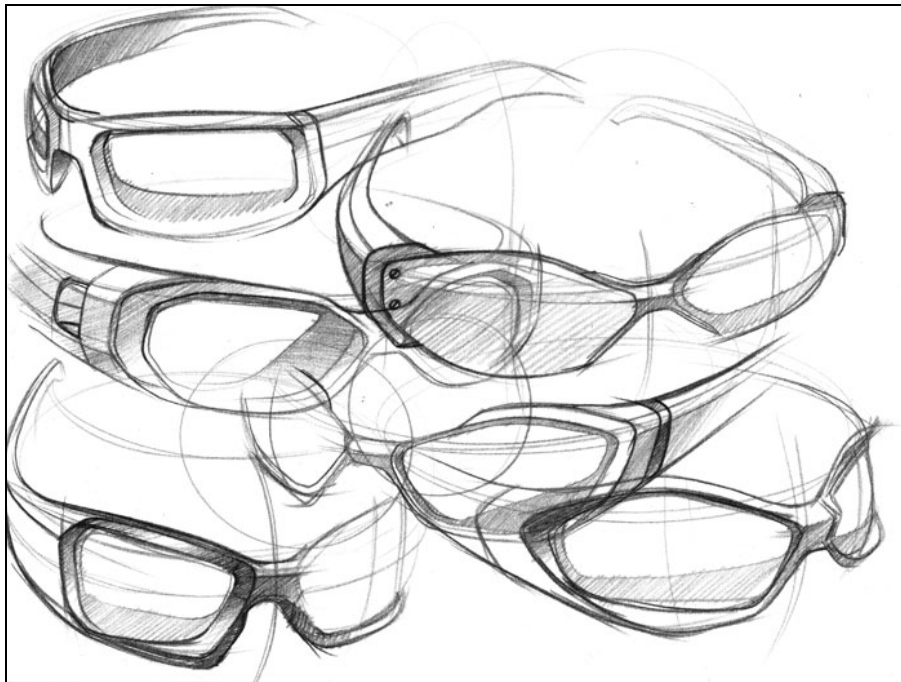


Figure 4.12 Example of hand sketching as design embodiment

Goldschmidt (Goldschmidt 2004 p203-217) relates the use of hand-drawn sketches to three stages of design practice: concept, development and detail design. She suggests that design drawing progresses through three stages of development, 'starting with rapid preliminary sketches, advancing to so-called "hard line drawings" and "presentation drawings," and finally technical construction or manufacture drawings' (ibid). Goldschmidt (Op cit) describes the rapid nature of the hand sketch and its ability to facilitate a generative design process.

Designers need imprecise external representations to interact with continually in order to make decisions and progress design during conceptualisation (Visser 2006 p133). Sketching is effective in allowing designers to work with incomplete information, making assumptions and provisional decisions that need to be revisited and reviewed. 'Imprecision (flexibility), ambiguity (alternative meanings) and abstraction (simplification) characterise the relationship between the actual and the possible solutions' (Dorta and Perez et al 2008 p123). The explorative nature of concept design practice and the kinds of embodiments made require a, 'fuzzy definitions due to the incompleteness of product definition within the early stages' (Romer and Pache 2001 p478).

A number of terms are used to describe the different kinds of embodied outcomes made through the use of sketching tools during concept design; 'referential Sketch', 'Shape Configuration Sketch', 'Generation Focused Sketch' (Figure 4.13). The referential sketch refers to another product or artefact in existence. A shape configuration sketch describes sketches used in the development of form and a generation focused sketch is used during concept design to quickly illustrate a variety of ideas. While not the only sketch types identified in the literature they were the three most often discussed with reference to concept design (Pipes 2007, Olofsson & Sjolen 2006, Pei et al 2009):

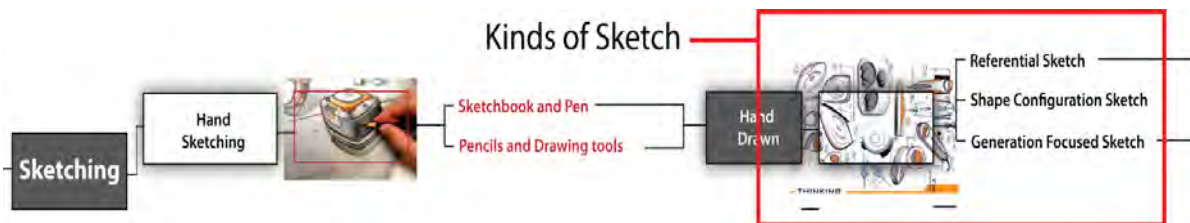


Figure 4.13 The kinds of sketches used to support design practice

Although the sketch is used throughout the design process, it is during concept design literature identified it as employed most often.

4.3.2 Digital Sketching

The taxonomy classified digital sketching as a tool that mimics the character of hand sketching but uses digital hard/software as the medium through which embodiments are made. The Wacom Cintiq graphics tablet⁷ is an example of such media. Digital sketching, like hand sketching, must, 'serve as a physical setting in which functional thoughts are constructed on the fly in a situated way' (Tovey et al. 2003 p139). However, the digital sketch also affords the functionality of digital technology through features such as layering, editing and various visual effects (Faber 2009). These affordances may also change the ways in which design embodiment progresses; the use of editing and undo functions for example (ibid). How or in what way the digitalisation of hand sketching influences the relationship between subject practitioner and design embodiment is a significant question. Figure 4.14 illustrates the use of Adobe's Sketchbook Pro digital sketching software, used with a graphics tablet during digital sketching:

⁷ The Wacom tablets allow the user to interact digitally in the same way as one might when using a conventional pen and paper: <http://www.wacom.com/index.html>

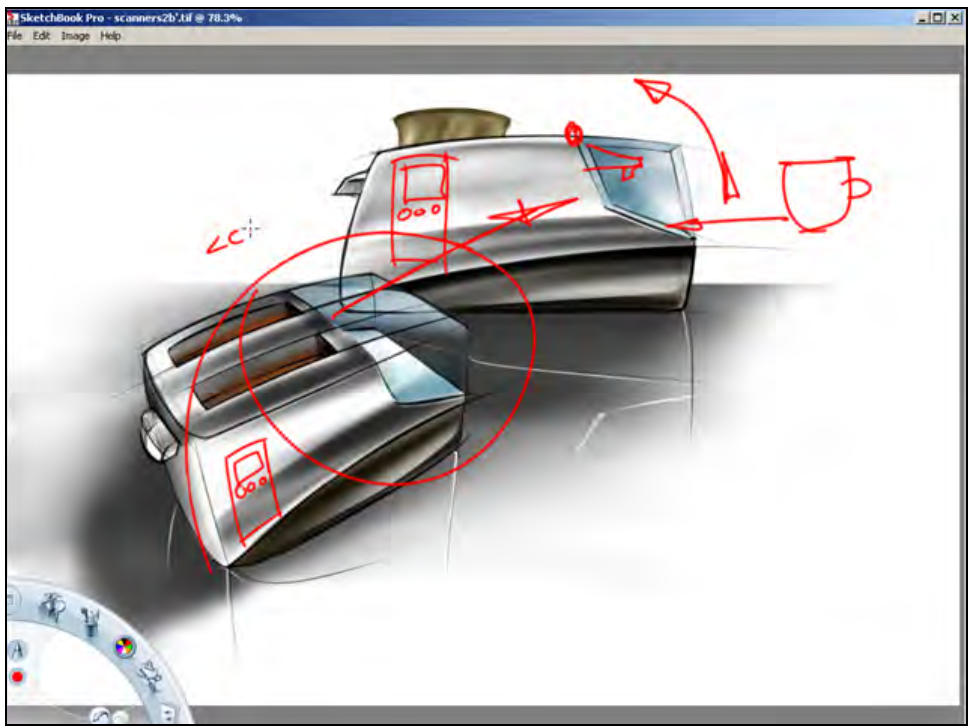


Figure 4.14 Image taken from graphics tablet using digital sketching software, SketchBook Pro

The literature review suggested that digital sketching tools were used most often during concept design. As with conventional hand sketching, the digital sketch was classified under 'Sketching' to reflect the use of the term within the literature as different from illustration and drawing (referring to a more specific type of embodiment such as a general arrangement drawing or rendering to help develop concept ideas). Figure 4.15 illustrates the place of digital sketching within the taxonomy:

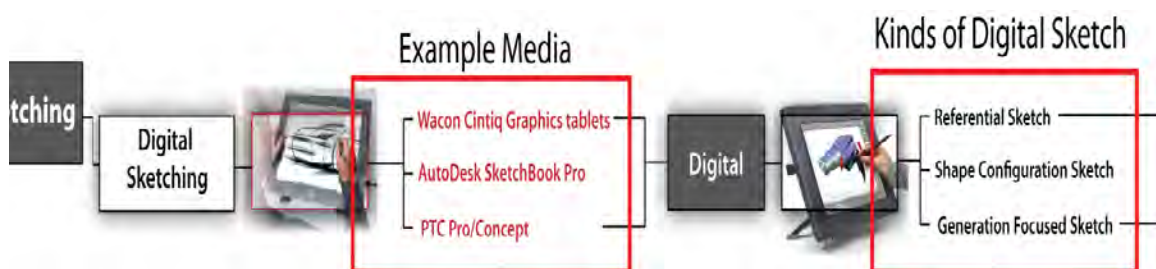


Figure 4.15 The kinds of digital sketching used to support design practice

4.3.3 Sketch Modelling

During concept design designers embody design ideas through the construction of quickly made physical models. As with the use sketching, these are fluid, low-fidelity embodiments made using craft-based skills and techniques. Like sketching, sketch

models are used in early design to quickly externalise and consider concept ideas: 'Physical models are an essential tool in developing judgment via critical evaluation and reflection' (Green and Smrcek 2005, p324).

Literature indicated that a variety of physical models are used to support the different requirements of studio practice. Velasquez-Posada (Op cit) considers the different types of model required during concept design and those used to support development and detail design activity:

3D physical models [sketch modelling] can be seen as merely the first stage in the exploration of a product idea or form, but they can also be used for presenting product ideas to the client through simulation of real materials.

(Velasquez-Posada 2005 p345)

Velasquez-Posada (Op cit) goes on to provide a classification for the techniques required when engaged in the construction of handmade models (Figure 4.16):

Table 1. Techniques classification.

Process	Characteristic	Material	Technique	Product
Adding material	Empty volumes defined by their planar faces	Paper tape	Glue layer by layer of the paper tape	Household plastic products
		Thin card board	Revolved surfaces	Bottles
		Thick card board	Descriptive geometry, templates and agglomerating material	Kitchenware
	Solid volumes made from agglomerating material	MDF	Serial planes, agglomerated or separated by regular gaps	Workshop tools
Subtracting material	Volumes cut off from a solid block	Polyurethane foam	Carving	Toys
		Balsa or soft wood	Carving	Vehicle parts

Figure 4.16 Velasquez-Posada's classification of conventionally made models

Model making is described as either a process of adding or subtracting material. A 'characteristic' column provides details of the nature of the model's structure (Figure 4.16). To the right of Characteristic, information on the materials used to construct

different types of models is presented. A 'Technique' column suggests that some of the skills and processes required in the construction of various models. To the right of this, 'Product' describes the kinds of artefacts often modelled through the use of the various materials and techniques (Figure 4.16). Figure 4.17 illustrates the use of sketch models made from polyurethane foam during design practice:



Figure 4.17 Styro-foam concept sketch model

The character of sketch modelling is often described as loose, fluid and dynamic (Velasquez-Posada 2005, Romer & Pache 2001). Like sketching, these characteristics relate to tool use during explorative concept design, 'In a cost-efficient way; without unnecessary loss of time; using 'fuzzy' definitions due to the incompleteness of product definition within the early stages' (Römer & Pache et al. 2001 p478). Conventional craft-based carving and shaping techniques are employed as the shaping of the material itself mediates design ideas in a physical form. The outcome is the physical embodiment of design intent that is quick and simple to construct, less constrained and open to change, thereby reflecting the dynamic nature of conceptualisation.

Sketch modelling is identified within the taxonomy as a physical 3D concept design tool under the sub-classification: 'Models & Prototypes'. Some examples of the mediating materials and techniques used in design embodiment as sketch models are presented (Figure 4.18, in red). The generic type of model outcome is described as 'Handmade Low-Fidelity':

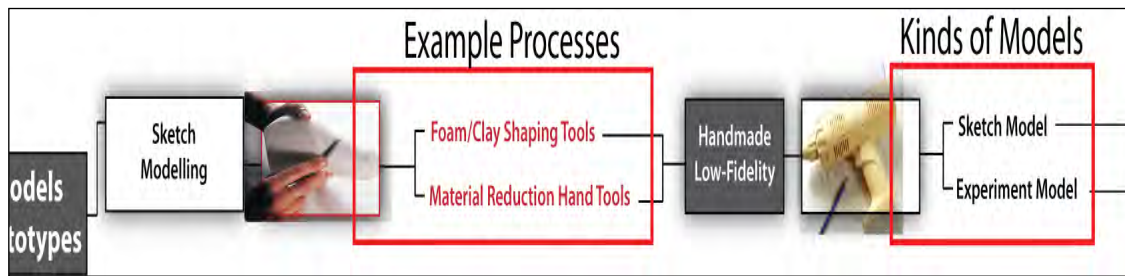


Figure 4.18 The kinds of sketch modelling used to support design practice

4.3.4 3D Printing

Digital 3D printing affords the rapid construction of three dimensional artifacts from digital data. The outcome of a process of 3D printing, like rapid prototyping, is design embodiment as a physical model⁸. The rapid speed of 3D printing and its comparatively low cost, when compared to other forms of rapid prototyping, make the medium more adapt at supporting concept design practice.

Block form digital models are used as geometry to produce a 3D print. 3D prints, like sketch models, have also been described as lower-fidelity (Haller & Cullen 2004). However, unlike the use of sketch modelling during design embodiment, models are constructed exclusively using digital processes. As the manipulation of design embodiments takes place through a digital interface, this process contrasts with the motor-skill driven nature of conventional workshop techniques in the construction of sketch models (McCullough 1997). The 3D print provides no opportunity for change during the process of construction. That is to say, the process of embodiment takes place prior to the automated process of printing. In this way there is no working through the tool of 3D printing during the making of the physical embodiment. Instead the designer interacts physically with the 3D print before returning to the digital environment to alter its form. Often the cycle of digital modelling and 3D printing will iterate (Hudson 2008). Figure 4.19 illustrates a small 'desk-top' 3D printer:

⁸ 3D printing is a form of additive manufacturing technology. A three dimensional object is created by successive layers of material. 3D printers are generally faster, more affordable and easier to use than other additive manufacturing technologies.



Figure 4.19 'Desk-top' 3D Printer

3D printing was identified and classified under concept design, although it may, like sketching, be used throughout the design process. 3D printing was also classified as a 'Modeling & Prototyping' tool. Examples of the kinds of media used to construct design embodiments as 3D prints were given. The generic type of embodied outcome of a process of 3D printing is termed 'Digital Low-Fidelity' (Figure 4.20). Some examples of terms used in the literature to describe 3D printed models are also given: 'Sketch Model', 'Experimental Model':

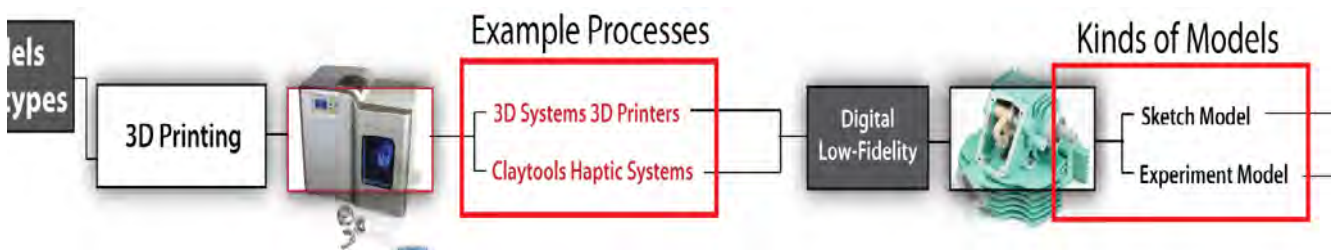


Figure 4.20 The kinds of 3D printing used to support design practice

4.4 Tools Classified under Development Design

During development design concept ideas are refined and developed in more detail. Digital design tools have had an increasing impact upon the developmental stage in practice. Conventional graphics tools, such as the hand-drawn marker rendering (Powell 1985) are used alongside hybrid and digital graphic illustrations⁹. Their place in

⁹ Digital 2D graphics tools such as the adobe suit (see footnote 10 below) are used to develop hand drawn sketch work in more detail for presentation to stakeholders.

the taxonomy does not indicate a prescriptive relationship between tool and stage in practice, but serves to suggest where they are used most often during the design process (concept, development or detail design). Digital and conventional graphics tools refer to media used to progress concept sketches and develop design intent in greater detail (Pipes 2007). Although they may also be used during concept design, literature indicated their use to evolve concept ideas and develop proposals in more detail as design progressed.

This is true for the design tool 3D CAD, also classified under development design. As with sketching, literature suggested that 3D CAD is used throughout development and detail design, and to a lesser extent during concept design, (Dorta et al. 2008, Pipes 2007, Guidot 2006).

The three tools identified as often used during development design were further classified under 'Drawings & Illustrations' and 'Models & Prototypes (although 3D CAD is not a physical embodiment of design intent, its use in practice to embody design ideas in 3D, albeit digitally, was reflected in the tool's classified). Figure 4.21 illustrates the taxonomy of the 3 tools:

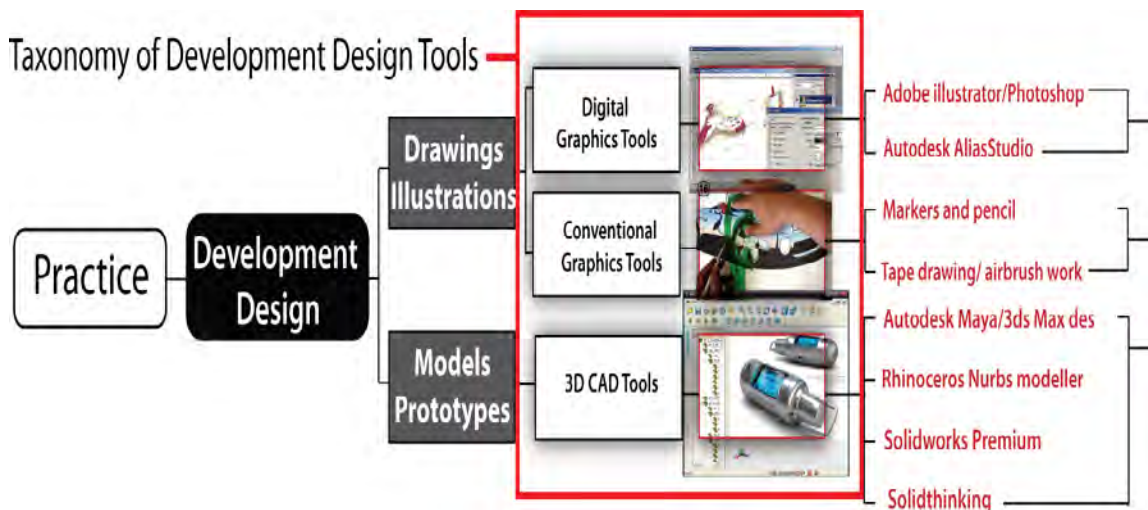


Figure 4.21 Classification of development design tools within the taxonomy

4.4.1 Digital Graphics Tools

An example of digital graphics tools used in the embodiment of design intentions is the Adobe suit¹⁰ of graphics software. Although digital graphics tools are also used during

¹⁰ The adobe software is a suit dedicated to graphic, photographic and web authoring design. Industrial designers also make use of this software for rendering and visualisation.

concept design, they were identified as employed most often to evolve design intent from initial concept towards more specific embodiment. In research to identify the design tools most used by industrial designers, Morris (2008) showed Adobe's Illustrator and Photoshop graphics software as most often employed by designers during their studio practice. Figure 4.22 illustrates the use of digital graphics software as initial concept ideas are rendered and developed:



Figure 4.22 Rendered using Adobe's Photoshop graphics tools

At a mid-stage between concept and detail design, industrial designers often employ design embodiments made through the use of hybrid digital/hand drawing tools (Pipes 2007 p19). In order to communicate evolving design intentions, designers employ digital graphics tools to manipulate previously made concept sketches or create wholly digital design embodiments. The types of software used to mediate embodiment as digital graphics was indicated in the taxonomy (Figure 4.23, in red) along with a term to describe the embodied outcome through the tool's use, 'Digitally Aided Illustrations':

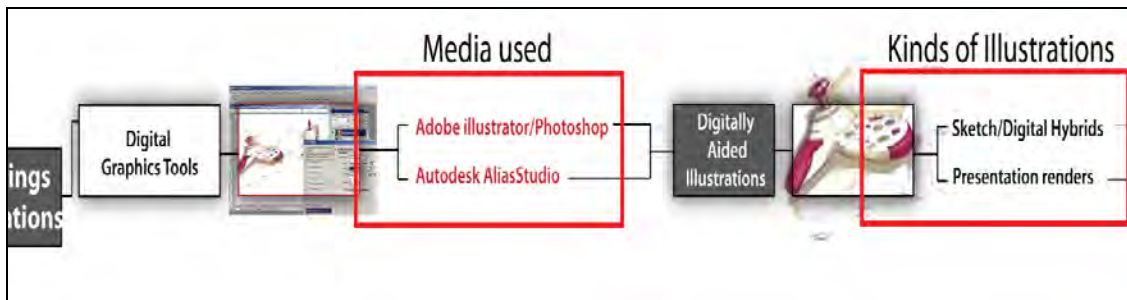


Figure 4.23 The kinds of digital graphics tools used to support design practice

4.4.2 Conventional Graphics Tools

'Every designer now has a computer, maybe more than one, but there is still a vital role for the more humble manual tools of the trade' (Pipes 2007 p92). Of the graphic marker, Powell (1985 p62) remarks that, 'of all the materials available to the designer the marker is probably the most widely used'. This remark is now dated, with the marker largely replaced by the use of digital graphics tools.

Conventional graphic representations are full colour refined concept sketches (Haller and Cullen 2004). These mid-stage design representations come downstream from conceptual design:

Later on during the process, designers employ a second type of representation, presentation sketches...to better communicate asynchronously to colleagues and clients the already designed proposals.

Dorta et al (2008 p124)

These mid-stage embodiments require a greater level of detail and consideration for component parts, 'Intermediate states would then have to be inner or external representations of candidate elements of the entity that is being designed' (Goldschmidt & Smolkov 2006). With studio practice moving to a more structured approach, the kinds of drawn embodiment used also change. Rodgers et al (2000 p452) makes a distinction between the drawing made as concept sketch, engineering drawings for manufacture and a mid-stage presentation drawing, 'The conceptual sketch is very different from the other types of drawing employed by designers: the presentation drawing and the drawing for manufacture'. McGown et al (1998 p444) considers the process of embodiment through graphic illustrations as less creative than that of sketching, 'Presentation drawings however are merely laboured reworking of

conceptual sketches, traced or more carefully rendered, perhaps with detailed graphics and text but not furthering the design.’ The use of conventional graphics tools will influence the character of the design activity, ‘abstract and more realistic visual representations such as perspectives may also be employed’. Figure 4.24 illustrates the use of conventional graphics tools as design intentions are developed:



Figure 4.24 Conventional graphics tools

Unlike digital graphics, conventional graphics tools use analog graphic illustrations to embody design intentions (Figure 4.24), although in reality analog and digital graphics tools are often used in a hybrid process of design embodiment. However, in terms of research aims, it was important to distinguish between different media in order to consider how tool characteristics may influence the kinds of embodiments made. The taxonomy identified ‘conventional graphics tools’ to distinguish between their digital counter-parts in order to explore how their use might influence practice:

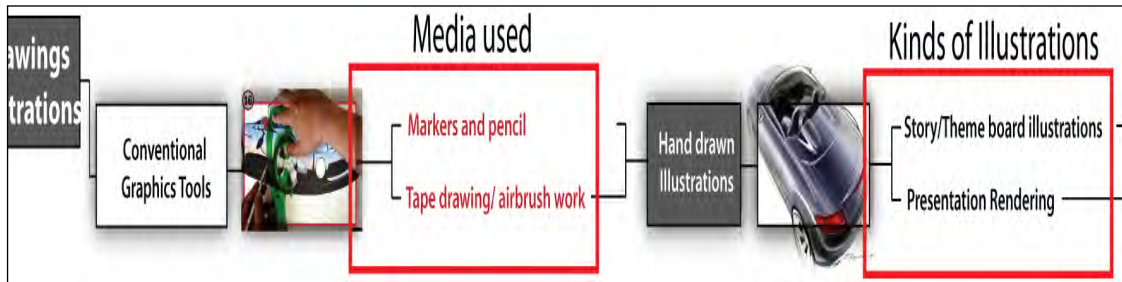


Figure 4.25 The kinds of conventional graphics tools used to support design practice

4.4.3 3D CAD Tools

3D CAD tools allow the designer to embody design intent in three dimensions but in the digital environment. The use of 3D CAD in practice is well established: 'In contemporary design, giving visual form to an object will more often than not involve the computer and various design packages such as 3D Studio Max' (Sass 2006). Powell (2007) predicts the growing influence of 3D CAD in its ability to penetrate conceptual design:

The greatest potential for three-dimensional systems lies in the difficult transition from idea to rough model many designers can easily articulate ideas through their heads but the difficulty lies in transcribing the ideas into three dimensions quickly and efficiently.

Powell (2007)

However, the use of 3D CAD is often limited during concept design (Tovey and Owen 2000). This is due to the nature of the media and its inability to augment the kinds of fluid conceptual embodiments required in support of concept design, 'Computers tend to be used more as styling proceeds, with greatest use after week 7' (ibid p570). Lawson (2004 p71) considers 3D CAD tools as of less use during conceptual design due to their inability to augment the construction of fluid representations, 'A general common sense account of experience with systems [CAD] is that they are not helpful tools to use while in the early stages of designing' (ibid). Figure 4.26 illustrates the use of 3D CAD software in the embodiment of design intent as a CAD model using Rhino nurbs-based modeling software:



Figure 4.26 Design embodiment through 3D CAD

Dorta et al (2008 p124) identifies the use of presentation drawings at a later stage in practice, coming after concept design, constructed through the use of 3D CAD, ‘digital three-dimensional models, drawings and images.’ These more realistic embodiments are often used at a stage after conceptual design as the design solution develops and, ‘other more structured forms of pictorial representation, such as plans or sections, become a part of the process.’ (ibid p389).

The term 3D CAD is used to describe a paradigm of existing software of various kinds used to generate 3D digital models, examples of these are illustrated within the taxonomy: AutoDesk Maya, 3ds Max, Rhinoceros, Solidworks, Solidthink. The generic term used to describe the embodied outcomes made through the use of 3D CAD is shown as ‘3D Digital Models’. Examples of terms used to describe these models are also represented in the taxonomy as ‘Design Development Models’ and ‘Presentation Models’ (Figure 4.27).

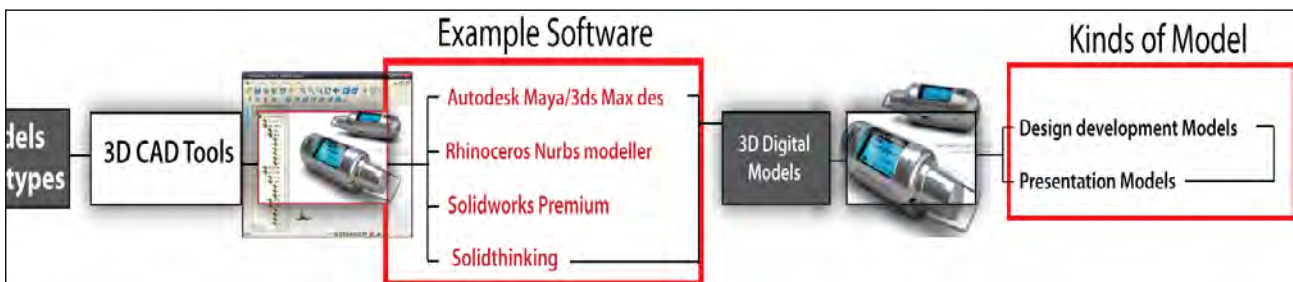


Figure 4.27 The types of 3D CAD tools used to support design practice

3D CAD was categorised under development design, although the literature suggests its use across design practice. However, rather than a prescriptive model of design tool

use in practice, the taxonomy was used as a way to develop understanding of relationships between design tools and their use within practice. As such, with the balance of literature indicated 3D CAD's use during development design as a tool to progress concept ideas in more detail, it was placed under 'Development Design'.

4.5 Tools Used During Detail Design Practice

Detailed design is concerned with the embodiment of specific details for the communication of design intentions to those responsible for manufacture (Slack 2006, Press & Cooper 2003). Accuracy and precision are key requirements. Unambiguous embodiment and communication of detailed information is a priority as assembly and engineering drawings are used along with models and prototypes to achieve this (Guidot 2006). Figure 4.28 illustrates the tools classified within the taxonomy under detail design:

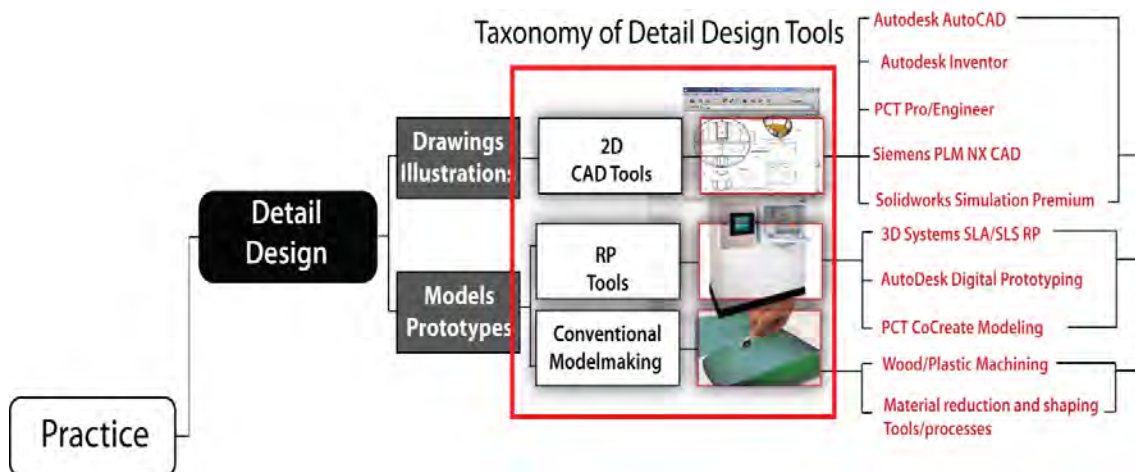


Figure 4.28 Classification of detail design tools within the taxonomy

Design progresses through a strongly vertical mode of transformation (Goel 1995 p125), that is the evolution of a focused design strategy rather than working across a number of design ideas. 'Unambiguous is the key word' (Pipes 2007 p156).

The embodiment of intentions during detail design uses the affording character of digital tools to communicate accuracy and consistency (Tovey & Owen 2000, Pipes 2007, Tovey & Porter et al. 2003). Three design tools were identified in the literature as often used during detail design practice: '2D CAD Drawing Tools', 'Rapid Prototyping' and, decreasingly, 'Conventional Model Making'.

4.5.1 2D CAD Tools

2D CAD is used to embody design intentions as detailed engineering drawings for manufacture (Goldschmidt & Porter 2004 p205), ‘representations composed of detailed technical drawings and rapid prototyping models....to communicate exact and definitive information to build the artifact’. Detail design is concerned with the detailed specification of design for manufacture, ‘the basis for the transformation of conceptual brainchild into real product’ (Slack p92). To achieve this 2D CAD tools are often used to communication intent as technical construction drawings for the maker or, ‘highly structured and detailed representations used to document a design that has been developed’ (Purcell & Gero 1998 p390). Design drawings during detail design have a singular purpose of unambiguous and detailed communication:

Engineering drawing has one purpose: to communicate a designer’s concepts to those responsible for manufacturing the components of the product and assembling them. As such, the drawings must be complete, reliable and, as I keep saying, unambiguous.

Pipes (2007 p156)

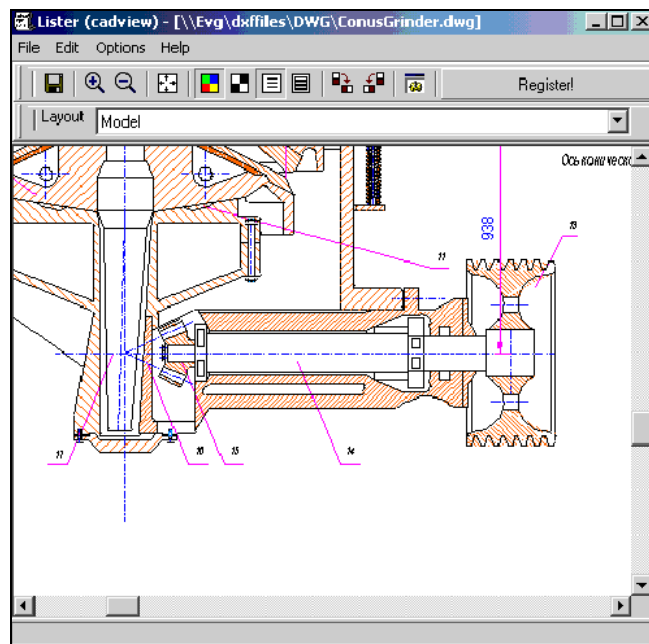


Figure 4.29 2D CAD tools used in the embodiment of engineering drawings

A variety of software is commercially available to mediate design embodiment through 2D CAD tools. The taxonomy identified five (Figure 4.30, in red). The generic term ‘Engineering Drawing’ was used to describe the kinds of embodiments made through

the tool's use (Cross 2008, Pei et al 2008, Pipes 2007, Haller & Cullen 2004). Five terms to illustrate the kinds of drawings made were presented in the taxonomy (Figure 4.30, right).

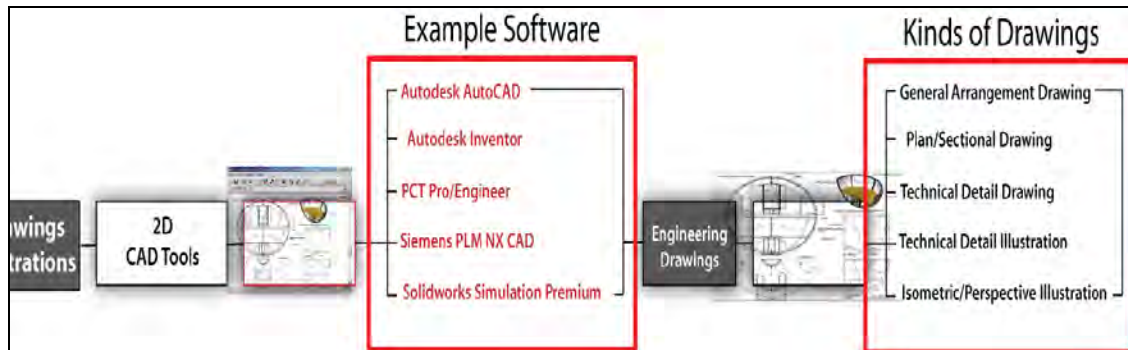


Figure 4.30 The types of 2D CAD tools used to support design practice

4.5.2 Rapid Prototyping Tools

The use of rapidly prototypes is now well established within industrial design practice (Sass 2006). During detailed design rapid prototyping is employed to create design embodiments as hi-fidelity models to prove a design proposal prior to manufacture. Rapid prototyping is also used during development design, although its cost can inhibit this (Dorst 2006). However, with decreasing costs of newer rapid prototyping technologies, this barrier seems to be receding.

There is no opportunity for the practitioner to interact with rapidly prototyped components during their production. The designer's manipulation of the design embodiment comes prior to production as digital modelling is used to represent design ideas. Figure 4.31 illustrates a rapid prototyping machine. This Selective Laser Sinter (SLA) uses a laser to solidify a powder composite, as it builds the parts layer by layer.



Figure 4.31 3D System's iPro 9000 SLA rapid prototyping machine

Within the taxonomy, rapid prototyping tools were classified as used most often during detail design and are further classified as 'Models & Prototypes'. The taxonomy illustrates some of the prototyping systems available and a generic term used to identify design embodiment as RP was employed 'Digital Hi-Fidelity Prototypes'. Finally, the kinds of terms used to describe design embodiments as rapidly produced artifacts are presented: 'Tooling Prototypes', 'Pre-Production Prototypes', 'Functional Prototypes' (Figure 4.32):

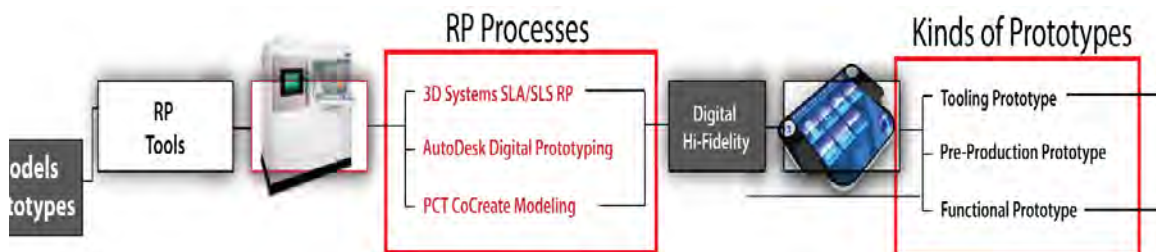


Figure 4.32 The kinds of RP tools used to support design practice

4.5.3 Conventional Model Making Tools

Conventional model making, through the use of workshop processes and material reduction techniques, is traditionally used to create physical embodiments of design intent. The accessibility of physical embodiment, as rapid prototype or handmade model, is an advantage when reflecting upon design intent, 'it is through the model, of course, that an idea reaches three dimensions for the first time, and both designer and client can truly access the design' (Velasquez-Posada 2005 p346). Handmade appearance models are often used as design progresses to communicate intentionality

in a physical form, 'used for presenting product ideas to a client through simulation of real materials' (Op cite). There is, however, a distinction between conventional model making techniques and prototypes produced using digital technologies. Slack (2006 p88) articulates this when considering the craft based motor skills required to construct conventional models and those produced using rapid prototyping technologies: 'Model making is a tool within the [product design] process that offers either a hands-on or a computerized methodology.'



Figure 4.33 Traditional model making techniques

The ways in which the designer may interact with and understand design embodiment through the use of conventional workshop processes when model making means an understanding of design intention is facilitated through a rich, physical interaction (Dorish 2001, McCullough 1997). However, digital tools may constrain the ability of the designer to think-in-action (Schon 1983).

During detail design, conventional workshop tools and processes are still used to construct three dimensional, physical representations. The various media used in the embodiment of design intent were illustrated as 'wood/plastic machining processes', 'Material Reduction' and 'Shaping'. The generic term 'Handmade Hi-Fidelity models' was employed to indicate the kinds of embodied outcomes often produced through model making during detail design. Examples were also given of the terms used within the literature to describe design embodiment through model making tools (Figure 4.34, far right):

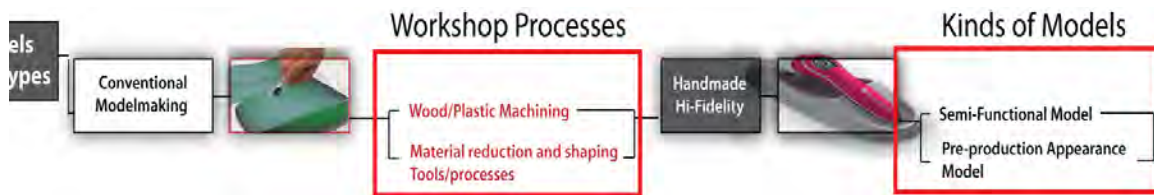


Figure 4.34 The kinds of conventional modelling tools used to support design practice

4.6 Discussion

The taxonomy indicated relationships between the tool and its ability to support the different requirements of studio practice. For example, sketching was often described as effective during concept design due to its ability to support an iterative and explorative engagement with design embodiment. Rapid prototyping was considered effective during detail design in its ability to support a more specific form of embodiment. The taxonomy of design tools constructed through a review of their use in practice suggests the character of the tool has influence upon its place of use.

It is acknowledged that the taxonomy has limitations. Often literature suggested tools were able to support all three stages of the design process (sketching and 3D CAD tools in particular). This indicated the classification of design tools within a three stage approach to practice is an over-simplification of their use. The model of Industrial Design Practice and Tool Use presented in Chapter 3 indicates a rich set of influences informing tool use during practice. The taxonomy does not well reflect these influences. In this way it is limited in its ability to fully describe the complexity indicated by model.

However, the taxonomy provided a starting point in mapping-out relationships between the kinds of embodiments made through the use of different design tools and how these relate to a relationship between the tool's character and the various requirements of practice.

Chapter Summary

A literature review of previous taxonomies of design tools was presented. This was followed by the presentation of a further Taxonomy of 10 Design Tools. The identification of the 10 tools and their classification within 3 generic stages of design practice was not prescriptive, but offered a means to start to explore relationships between design tools and the context of their use in practice. A review of literature on the use of design tools to embody intent at various stages in practice, suggested that

many are employed to support different requirements across studio practice. Moreover, the hybrid use of tools is common, and sketching in particular may be used in combination with digital graphics tools. The use of rapid prototyping and 3D printing must necessarily require the use of 3D CAD tools of embodiment prior to the production of prototypes. As the Model of Design Activity and Tool Use presented in Chapter 3 indicated, thinking about design tools in terms of relationships between the tool and context of use (design process) alone neglects the influence of the designer's own approach to the use of tools in the context of their own background, experience and the ways working culture and the wider context of tool use may inform design activity.

Rather than representing an exacting illustration of tool use in practice, the taxonomy provided a platform for considering relationships between various tools and their context of use within the design process (concept, development and detail design).

Chapter 5: Universal Characteristics of Design Tools

Introduction

Chapter 4 introduced a taxonomy of 10 design tools which suggested relationships between the character of various tools and their use in support of concept, development and detail design.

This Chapter presents 5 universal tool characteristics (UTCs) identified through literature review. These characteristics were employed as a means to describe the affordance and limitations of the design tools classified within the taxonomy in supporting the identified stages of design practice (concept, development and detail design). The tool characteristics provided a means through which relationships between the design tool and their support of practice were considered. The use of the 5 reflected emergent themes and principles identified a literature review, and served, along with the taxonomy, as an approach for exploring the designer's attitudes towards choice and use of design tools. However, the aim was not to identify any best approach to the use of a given design tool, rather they provided a framework to first identify relationships between design tools and their use in practice and then analyse designer attitudes towards these relationships (Chapter 6). The objective was to explore designer attitudes towards design tools to better understand relationships between the principles identified within the Model of Design Activity and Tool Use (Chapter 3).

The first section of this Chapter presents a justification for the use of Universal Tool Characteristics in the investigation of practitioner attitudes towards the tools identified within the taxonomy (Chapter 4). This is followed by an overview of the 5 tool characteristics, their identification in source literature and synthesis. Following this, a detailed description of the 5 UTCs with reference to source literature is presented.

5.1 Tool Characteristics: Opportunity for Investigation

The Model of Design Activity and Tool Use (Chapter 3) provided a theoretical framework for the study of design tools. The taxonomy of tools suggested a relationship between the character of the tool and its use in practice. Having identified a number of recurrent themes describing the character of design tools within the literature, an opportunity existed for using these principles to analysis the relationship that tool use has to practice through exploration of designers attitudes in terms of the 5 UTCs.

Despite a considerable body of work describing relationships between design tool character and effective support for studio practice, fewer studies were identified that explored the critical influence that the designer's own idiosyncratic choice and use of tools has during design activity. Based on these findings, the identified universal characteristics were used to analyse designer attitudes towards the various tools classified within the taxonomy (Chapter 6). Boundaries and constraints were needed to guide an investigation of attitudes towards tool use which could then be employed in the analysis of data. The identification of the 5 UTCs was seen as providing these necessary boundaries through which attitudes could be assessed.

The 5 UTCs were identified through literature review of design as a situated, reflective practice (Schon 1983); design as a cognitive activity (Visser 2006, Goel 1995); the role of design representations in design practice (Goldschmidt & Porter 2004); and a body of work relating to the designer's sketch (Bilda, Demirkan 2003a, Goldschmidt 1992, Jonson 2005, Menezes & Lawson 2006, Dahl & Chattopadhyay et al. 2001). Within these fields, common themes, describing the character of design tools emerged. These themes were termed Universal Tool Characteristics (UTCs) to reflect discussion in the literature suggesting their applicability to all tools to varying degrees.

The UTCs were then used as a vocabulary through which tools identified within the taxonomy (Chapter 4) could be accessed by the designers. To what extent did each of

the tools provide an opportunity to support design activity that might be described by the 5 universal tool characteristics?

Restricting the analysis of attitudes to the 5 identified characteristics posed two concerns. First, that the identified UTCs might constrain designers' in their ability to fully express their attitudes towards and use of tools. Second, by restricting the designers' vocabulary of expression, other significant factors would be missed. To offset these concerns, a further investigation of practitioner attitudes was planned to gather further qualitative data using open-ended questions during an interview study (Chapter 8). The aim of the use of the taxonomy and UTCs to analyse designer attitudes was to provide an opportunity to investigate some of the complex relationships identified in the Model of Design Activity and Tool Use (Chapter 3). Rather than a prescriptive means to investigate designer attitudes, the UTCs represented a set of variables through which approached to tool use might be explored.

5.2 UTCs: An Overview

The 5 UTCs, identified through literature review, were termed:

1. Mode of Communication
2. Level of Ambiguity
3. Transformational Ability
4. Level of Detail
5. Level of Commitment

Table 2 provides a summary of the terms used to describe each UTC (left) along with a short descriptor of the individual characteristics (centre) and the terms of reference used within the source literature to describe each characteristic (right):

Characteristics	Descriptions (of UTCs)	Terms of Reference	
1. Mode of Communication	To what extent the design tool supports the communication of design ideas to others	Dorta et al (2008)	self-reflective mode
		Schon (1986)	representation, analysis, emergence
	To what extent the design tool supports reflection-in-action and the emergence of design ideas	Goldschmidt (1997)	dialogue with self
		Jonson (2005)	I-representations

2. Level of Ambiguity	To what extent the design tool supports the ambiguous representation of ideas	Fish (2004)	vagueness
		Goldschmidt (2004)	Unstructured nature
	To what extent the design tool supports the unambiguous representation of ideas	Goel (1995)	Ambiguity/ Density
		Visser (2006)	unspecific
3. Transformational Ability	To what extent the design tool supports movement from one design idea to a new idea – horizontal transformations	Goel (1995)	Transformation
	To what extent the design tool supports movement from one idea to a variation of the same idea – vertical transformations	Visser (2006)	duplicate, add, detail, concretize, modify, revolutionize
4. Level of Detail	To what extent the design tool supports a high or low Level of Detail	Brereton (2004)	kinds of information available
	To what extent the design tool supports an overall or artistic impression of form	Visser (2006)	precision
		Goldschmidt (1997)	Less/more specific
5. Level of Commitment	To what extent the design tool communicates a higher level of commitment to design ideas	Goel (1995)	Early Crystallisation/ completeness
		Pipes (1990)	More Committed
	To what extent the design tool communicates a lower Level of commitment to design ideas	Powell (2007)	less committed
		Tovey (2003)	uncommitted/ more committed

Table 2 Table showing UTC's, short descriptors and terms of reference at source

For example, relationships each of the UTCs has to design tools may be thought of in terms of the tools' ability to support activity described through answer to the following questions:

1. Is a given tool used most often to support self reflective design activity or is it primarily used to communicate intentions to others (Mode of Communication)?
2. To what extent does the tool afford the ambiguous/unambiguous embodiment of design intentions (Level of Ambiguity)?
3. To what extent does the tool allow movement from one design idea to another, or development of a single design direction (Transformational Ability)?

4. How specific is the embodiment of design intentions through the use of the given design tool (Level of Detail)?
5. How committed do design intentions appear to be in embodiment through the use of a given tool (Level of Commitment)?

All design tools may be described as supporting a combination of the 5 UTCs, but it was the extent to which the designers rated the 10 tools identified in the taxonomy in their support of the UTCs the research aimed to explore. The placement of design tools within the taxonomy was then considered against practitioner attitudes towards tools in terms of the UTCs.

5.3 The UTCs of Sketching Tools

A number of studies were identified on the effectiveness of sketching during studio practice. As an example of the application of UTCs to describe the character of design tools (based upon existing accounts of the use of sketching in practice, as opposed to empirical data generated through this study), the sketch may be described as affording design activity that supports reflection-in-action; is considered ambiguous to allow movement from the embodiment of one design intention to new ideas (lateral transformations); is less specific in the embodiment of detail (Level of Detail); and suggests less commitment to design intent (Level of Commitment). Given this, hand sketching, as tool for design embodiment, is effective in supporting divergent concept design.

Through the research described in Chapters 6, 7 and 8, the UTCs were used as a vehicle to explore designer attitudes towards design tools. And to then consider what these attitudes may tell us of the relationship between the designer's approach to design activity and tool use.

5.4 Description of 5 UTCs

Each of the 5 UTCs is now discussed with reference to their identification and synthesis from the source literature.

5.4.1 Mode of Communication

Mode of Communication refers to the tool's use for the communication of design intentions. The term 'modes' was used to describe a distinction between the communication of design intent to other stakeholders and communication to oneself during a process of reflection-in-action (Lawson 2004, Schon 1983, Figure 5.1):

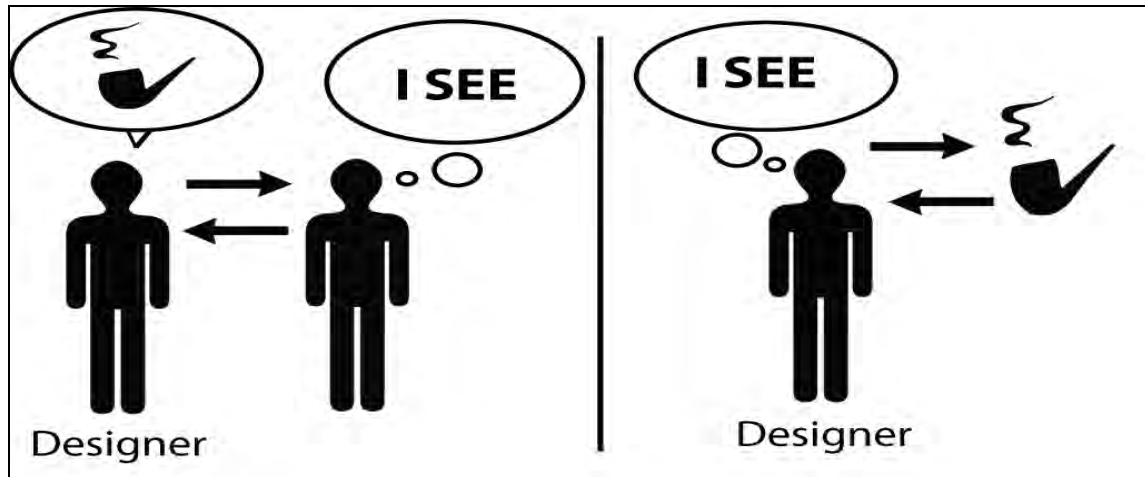


Figure 5.1 UTC: Mode of Communication. Communication to other stake holds and/or communication to oneself through reflection-in-action

In Figure 5.1 the designer communicates design intentions via design embodiments to others (client, engineer, stakeholder, left). To the right (Figure 5.1) the designer is illustrated reflecting upon design embodiment in order to consider and progress design ideas. This self-reflective design activity, or conversations with the embodiment of ideas (Lawson 2006) is a dynamic interplay between designer and the physical embodiment of externalised design intent through the use of the design tool. The process of design embodiment is used as a mediator between the practitioner's own thoughts and the externalisation of those ideas in physical form. Schon (Op cit) considers reflective practice as critical to the designer's engagement with the situated process of designing through the modelling of design intent using design tools, 'He shapes the situation, in accordance with his initial appreciation of it, the situation 'talks back', and he responds to the situation back-talk' (Schon, Op cit p79). Design embodiments may be used in both Modes of Communication. However, it was the extent to which a tool is used to support each Mode of Communication, in the view of designers, the investigation hoped to explore. This then provided a means, along with other UTCs, of analysing designer attitudes towards the tools within the taxonomy (Chapter 4). Figure 5.2 illustrates the use of hand sketching in the embodiment of

design intent as the practitioner reflects upon the sketch to understand, communicate and progressing design intent:

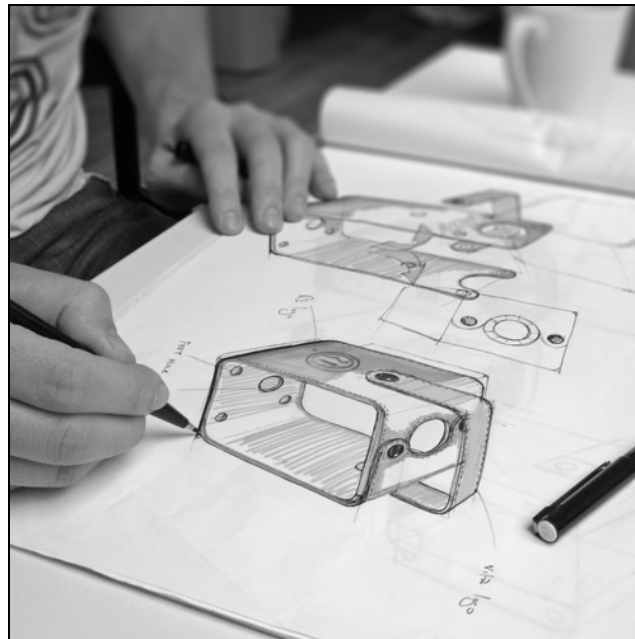


Figure 5.2 Designer engaged in reflection-in-action

A representation may also be required to communicate design intention to others. Badke-Schaub and Frankenberger (2004 p105-126) describe the importance of this communication with stakeholders, 'the designers were working individually about 70% of the entire working time. However, nearly 90% of critical situations occurred during instances of collaboration' (ibid). The suitability of various design embodiments to effectively support the communication of ideas is also described (Op cit), 'The chosen representation of design information has to suit many requirements of very different design situations in order to provide the necessary availability of information'.

Goldschmidt (2004 p203-217) refers to the importance of the external embodiment of ideas and the significance of those used to communicate intentions to others and those employed to support reflective practice: 'When a designer works with others or reports to them, external representation is mandatory, of course – communication depends on it; but the dialogue the designer conducts with him or herself, is no less significant.'

Design representations can be described in terms of their use in supporting the consideration of design intentions in a personal process of reflection-in-action and/or in supporting the mediation of design proposals to others. The use of design tools will

often involve both Modes of Communication. That is to say tools are all to a greater or lesser extent used by the designer to both reflect upon design intentions and present those intentions to others. However, literature indicated the use of some design tools as weighted towards reflective practice, with others described as being used in the communication of intent to others. In the use of Mode of Communication as a principle for investigating practitioner attitudes towards design tools, the research aimed to gather data on the designers' use of the tools identified in the taxonomy to support reflection-in-action and/or the communication of design intent to stakeholders.

5.4.2 Level of Ambiguity

Ambiguity refers to the design tool's use to support design embodiment that may be characterised by greater or lesser ambiguity. Ambiguous embodiment has been characterised by three types of indeterminacy: generality, vagueness and ambiguity:

Generality occurs when an idea that may be descriptively precise specifies a category with many exemplars. Vagueness occurs whenever there is a need to specify structure, form or colour approximately for later refinement. Ambiguity occurs when a choice has not yet been made between two or more alternatives.

Fish (ibid p151)

The research employed Level of Ambiguity to examine practitioner attitudes towards the design tools' use in support of ambiguous embodiment. The term ambiguity draws upon Fish's (ibid) notions of generality and vagueness to consider to what extent the design tool supports, on the one hand, a vague undefined embodiment of intent and on the other, the prescriptive, unambiguous representation of design ideas. The ways design tools are used will fall between these two poles. Their embodiment of ambiguity will depend on the pragmatic requirements of studio practice (stakeholder expectations, working culture) and the designer's own background (expertise and working habits) as on the character of the tool in use. In using ambiguity to analyse designer attitudes towards design tools the researcher aimed to explore the designer's approach to ambiguity when employing a variety of tools.

An example of ambiguity in embodiment is illustrated below in the ‘rabbit-duck’ illustration (Figure 5.3). The illusion was first noted by Jastrow¹¹, who suggested perception is more than a product of external stimuli, but also a mental activity. Industrial design tools model design intentions prior to manufacture. How fixed these embodiments are perceived to be, through a combination of external stimuli (design embodiment) and mental activity (the designer), has influence upon the ways the design tool is used and the kinds of design activities performed.

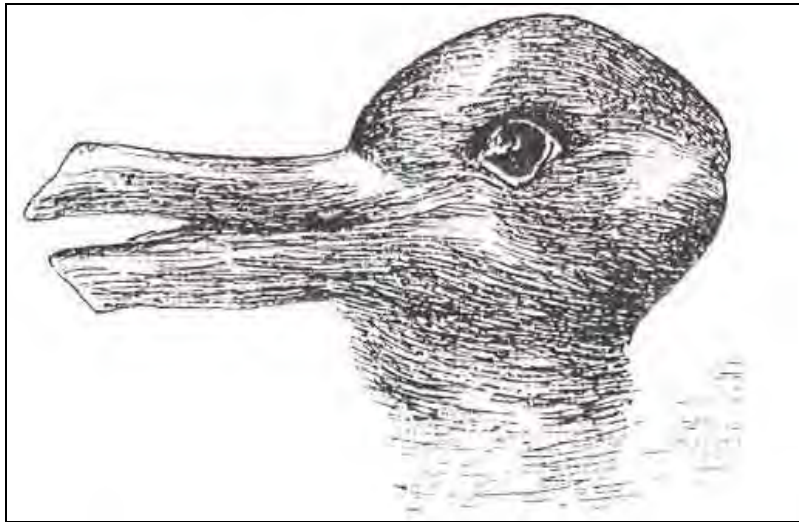


Figure 5.3 The rabbit-duck illusion. An illustration of ambiguity in representation

In a discussion describing the abstract verses concrete nature of design embodiments, Brereton (2004) considers various Level of Ambiguity in design representation, ‘Representations describe designs at various levels of abstraction. On the more abstract end of the scale lie lists of requirements, sketches, and models.’ The designer’s sketch in particular has an ability to support ambiguity, and so is seen as effective during concept design (Brereton 2004, Visser 2006). Figure 5.4 illustrates the embodiment of design intentions through often ambiguous design sketches:

¹¹ Jastrow's cartoon was based on one originally published in *Harper's Weekly* (Nov. 19, 1892, p. 1114) which, in turn, was based on an earlier illustration in *Fliegende Blätter*, a German humor magazine (Oct. 23, 1892, p. 147).

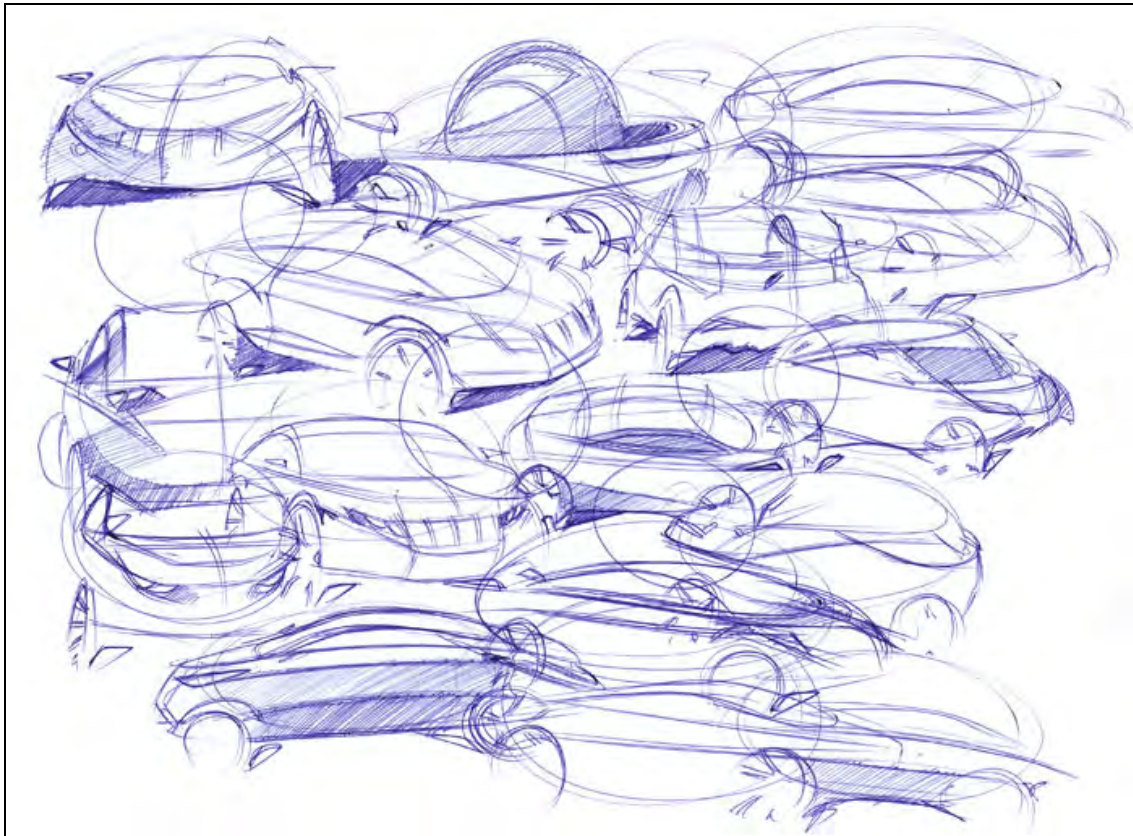


Figure 5.4 The design sketch and ambiguity in design embodiment

Goel (1995 p193), in a comparative study of sketching versus digital graphics tools, describes the importance of ambiguity at the front end of studio practice. He concludes that ambiguity in design embodiment is critically important to the explorative nature of conceptualisation. Without it there is a danger of the early crystallisation of design ideas and constraints on the generation and exploration of design options:

Ambiguity of the symbol system of sketching insures that the referents and/or contents of symbols during the early phases of design are indeterminate. Ambiguity is important because one does not want to crystallize ideas too early and freeze design development.

(Goel op cit, p.193)

Ambiguity in embodiment decreases as design progresses through the design process. This decreasing ambiguity is compared by Tovey et al (2003) to a gradual focusing of intent:

The process of moving from an initially vague concept to a detailed design proposal can be likened to moving from an out of focus image to one that is fully detailed. The concept sketch as an initial representation of the out of focus design idea is clearly essential.

(Tovey et al. 2003 p138)

During a focusing of design intent various design tools are used to embody design ideas with varying degrees of ambiguity, from design sketching through graphic illustration to 3D CAD and rapid prototyping (Pipes 2007). Ambiguity is necessarily reduced as the design progresses, with the perceived ability of the design tool to support these varying degrees influencing its use in practice.

Ambiguity in design embodiment can manifest itself through the tools that the industrial designer chooses to use and how s/he chooses to work with them. In principle, any design tool may be employed to embody design intent at any stage of the design process. Through the investigation of designer attitudes towards a tool's ability to support ambiguity, the research aimed to go beyond the analysis of the relationship between tool and a convergent studio practice, to investigate other related factors indicated in the Model of Design Activity and Tool Use (Chapter 3); in particular the influence of the designer and their idiosyncratic approach to tool use

5.4.3 Transformational Ability

Transformational ability refers to, on the one hand, the tool's use in the embodiment of a variety of design ideas and, on the other, an evolution of a singular design direction. Transformational ability relates to the requirements of studio practice; from divergent concept design to convergent detail design, and the effectiveness of various tools in supporting these different ways of working. This process of working across a variety of concepts, or constraining practice to the development of a single direction was termed Transformational Ability. Figure 5.5 illustrates transformation during design practice:

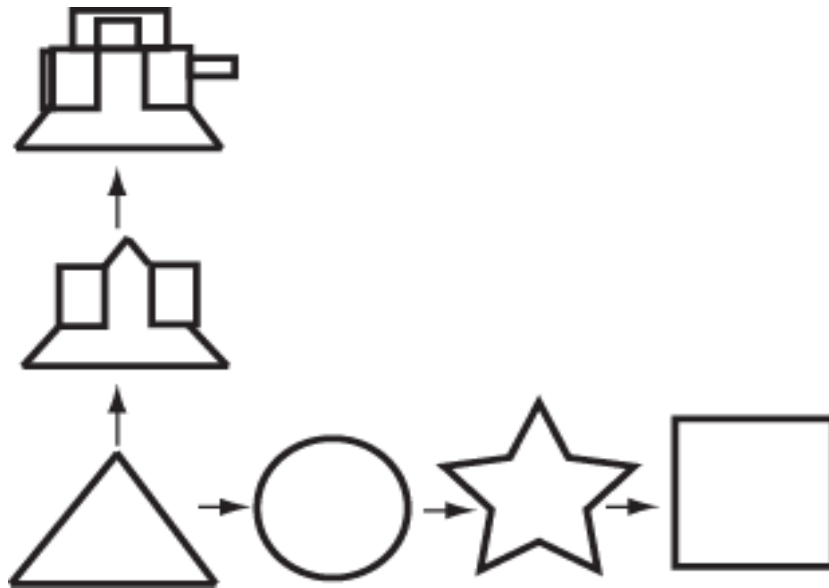


Figure 5.5 UTC Transformational Ability. Movement from one idea to a new idea and/or work on variations of the same idea

The two types of transformation are lateral and vertical (Goel 1995 p125). Lateral transformation describes an ability to move from one design idea to a significantly different idea. Vertical transformation is movement from one idea to a more detailed version of the same idea:

A lateral transformation modifies a drawing into another related, but distinctly different, drawing...A vertical transformation reiterates and reinforces an existing drawing through explication and detail.

(Goel op cit p210)

Design tools have the ability to support both modes of transformation to varying degrees. It was, however, the investigation of designer attitudes towards the degree to which lateral and/or vertical transformation is supported in the use of a given tool that the research explored.

The tool's ability to support one axis of transformation over another relates to the UTC Level of Ambiguity (see above). Ambiguous design tools of embodiment, such as sketching, effectively support lateral transformations, allowing a number of design intentions to be explored concurrently: 'Lateral transformations are necessary for widening the problem space and exploring and developing kernel ideas' (Goel 1995 p125). Other tools constrain practice to a single direction, employing unambiguity in the

embodiment of design intent. Goel (ibid) describes CAD drafting tools as more constrained and unambiguous, reflecting the nature of a detailed stage of practice, 'They are characterized by the concrete nature of information being considered, a high degree of commitment to generated ideas, attention to detail, and large numbers of vertical transformations.' Figure 5.6 illustrates the use of CAD modelling software in the vertical transformation of design intent as proposals are progressed during detail design.

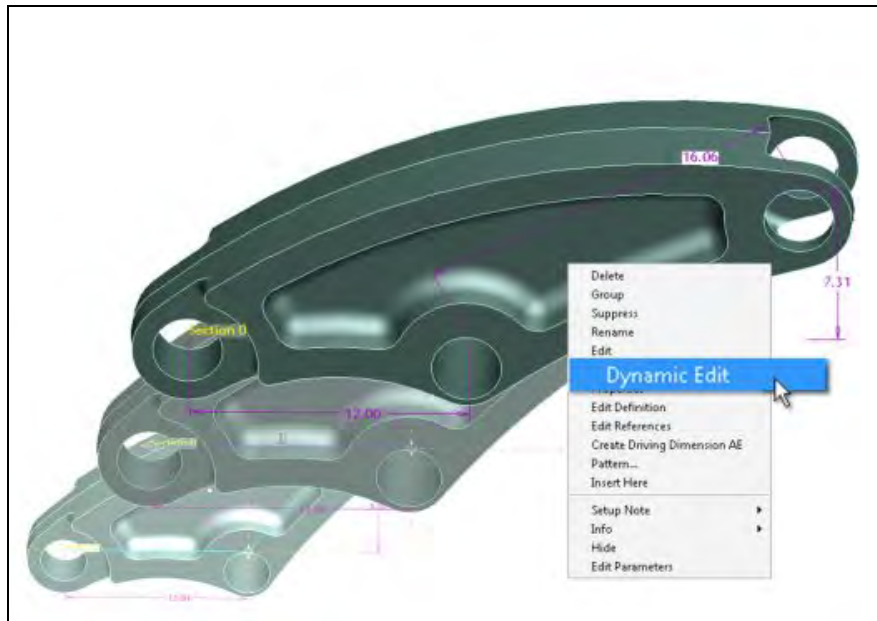


Figure 5.6 The vertical transformation of design solution ideas through CAD tools

Goel (Op cit p125) considers the relationships between transformational ability and design practice in the reduction of lateral transformation to be replaced by vertical as design progresses through design phases from problem structuring, preliminary design to design refinement and finally detailing. A diagrammatic representation of Goel's position can be seen in Figure 5.7:

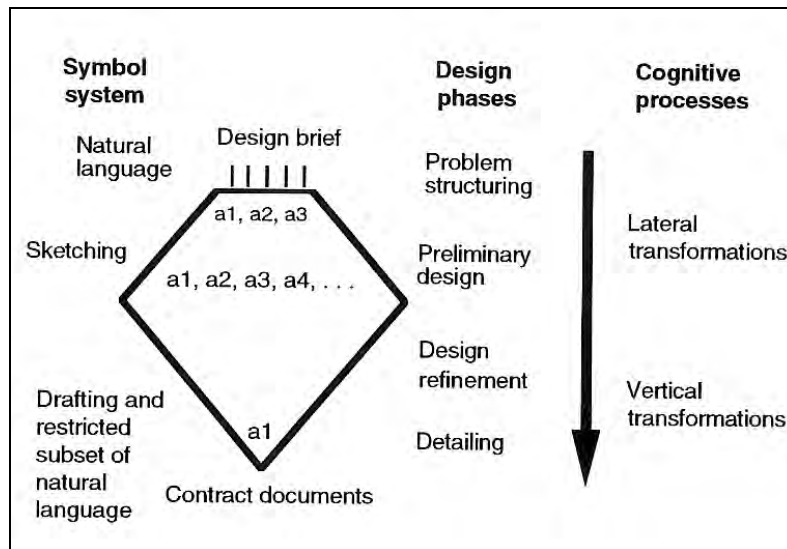


Figure 5.7 Goel's modes of transformation as they relate to design embodiment (Symbol systems), design process (Design phases)

Visser (2006) further divides Goel's (Op cit) transformations to distinguish: duplicate, add, detail, concretize, modify, and revolutionise during transformation:

Both transformations into different versions (through modification) and into alternative representations (through revolutionizing) constitute 'lateral' transformations. Vertical transformations (which, in his [Goel] terms, introduce 'detail') cover what we call both 'detailing' and 'concretizing.

Visser (2006 p194)

These terms relate to Level of Ambiguity and Level of Detail as they are used to indicate the different requirements of practice (Visser 2006, Rodgers & Green et al. 2000).

The use of the design tool in its ability to support vertical and/or lateral transformations, together with Mode of Communication; Level of Ambiguity and Level of Detail relate to the nature of design activity as it informs and is informed by the various requirements of the design process. Design is dictated by design purpose, to generate initial design ideas during concept design for example, with the designer choosing the design tools seen as best suited to support a specific design activity in the pursuit of achieving purpose.

5.4.4 Level of Detail

Level of Detail refer to degrees of specificity in the embodiment of design intent, how much information is made available and how focused and prescriptive is it? Figure 5.8 indicates the Level of Detail between design embodiments as sketch models and engineering drawings (see taxonomy, Chapter 4). To the left design embodiment as exploded drawing communicates higher Level of Detail compared to the low-fidelity sketch model, providing an impression of form and volume (Figure 5.8):

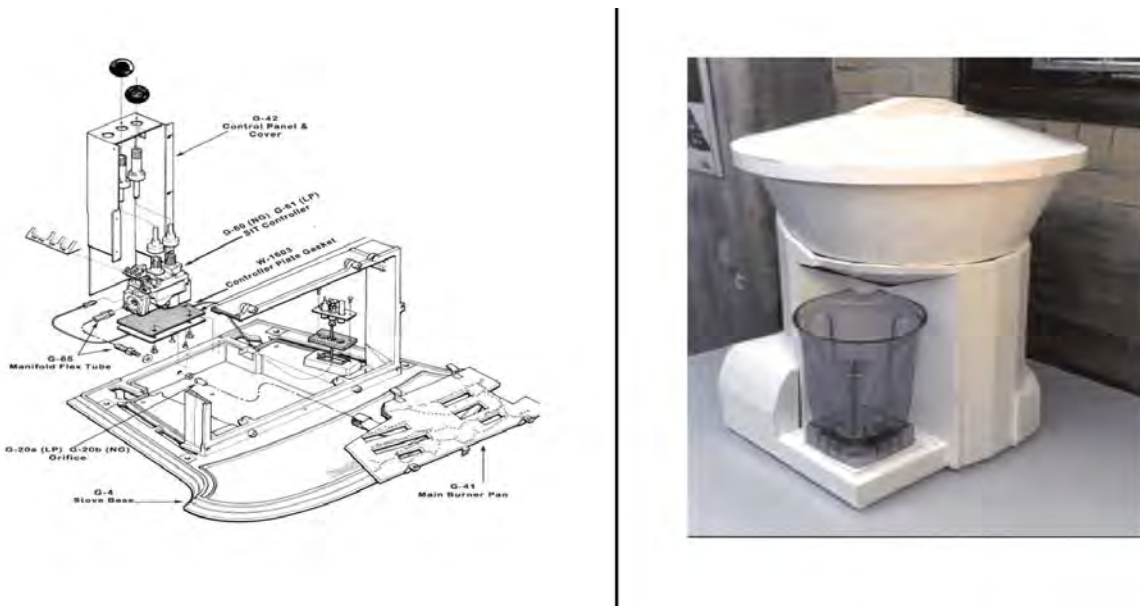


Figure 5.8 Contrasting Level of Detail seen through the use of different design tools

The embodiment of information that is less complete or makes less specific information available is useful during concept design to support the generation and exploration of design ideas (Goel 1995, Pipes 2007). Brereton (2004 p83-103), when considering the effectiveness of tools to support conceptualisation suggests, 'they do not force the designer to pay attention to details that the designer is not yet ready to consider'. Brereton (ibid) notes how the embodiment of ideas, through various tools, may influence communication of information to stakeholders, 'Different representations make different kinds of information available' (Op cit, p.86). Interaction between the designer and design embodiment is influenced by the character of the mediating design tool, 'The way in which designers must interact with representation in order to get the information that they need is an important factor for determining the usefulness of a representation' (Op cit).

Visser (2006 p153) uses the term 'precision' to describe the Level of Detail present in the embodiment of design intent. She also suggests that at the front end of practice

designers require the imprecise representations afforded through the use of sketching. And that it is, 'only gradually, as design progresses, are initial representations translated into representations with increasing degrees of precision.' As practice progresses from a more open conceptual design, through to the constraints of detail design, different tools are used (Pipes 2007), 'the back of the envelope initial concept sketch' (ibid p114) to the prescriptive embodiment of design proposals through 2D CAD engineering drawings (Op cit).

Level of Detail refers to the amount of attention paid to the communication of information, from the exacting prescription of design solutions to a general design overview. The amount of design detail articulated depends on the design tools used to communicate ideas, and also upon the designer's own idiosyncratic way of working, the purpose of the activity.

The characteristic Level of Detail has parallels with the principles discussed in the tool's ability to support ambiguity. However, Level of Detail differs from Level of Ambiguity in that the term is used to describe the embodiment of more or less specific information. The higher the Level of Detail, the more specific the information becomes. Intuitively, but not necessarily in the view of design practitioners (see Results, Chapters 7 & 8), the more detail available the less ambiguous the communication of ideas may become. The term ambiguity is used to denote opaqueness, i.e. the ability of the observer to make a subjective judgment on the design through its ambiguous representation. For example, the embodiment of a mobile phone concept that is ambiguous will not necessarily communicate high levels of 'mobile-phoneness'. A design representation of low specific detail may communicate the characteristics of a mobile phone clearly, but may not show, for example, a clear arrangement of the user interface. Tools used to support design intentionality will embody a mix of these characteristics dependent upon the requirements of practice at a given stage in design development.

5.4.5 Level of Commitment

Level of Commitment refers to a tension between the designer's wish not to crystallise design intentions too soon and the need to continually move the design forward, communicating progression to other stakeholders (Baxter 1995, Pipes 2007, Powell 2007). The more committed embodiment becomes, the less open practice is to the

introduction of new ideas. The Level of Commitment to design may be evaluated through, 'the nature of the written/drawn material' (Goel 1995 p113). Goel describes the character of the design proposal in its communication of a certain level of 'completeness' which has commonality with UTCs Level of Detail and Level of Ambiguity. Level of Commitment describes the embodiment of design ideas that may be perceived as closer to or further away from the manufactured artefact. Figure 5.9 illustrates the use of the design tool identified in the taxonomy as 3D CAD and the ways in which it may communicate a higher Level of Detail than the designer intended (Pipes 2007, Goel 1995). The designer presents the design embodiment as a 3D CAD model to the client. Although the design is not complete in terms of requirements for manufacture, the client perceives the design as more complete and less open to divergent change (Figure 5.9).

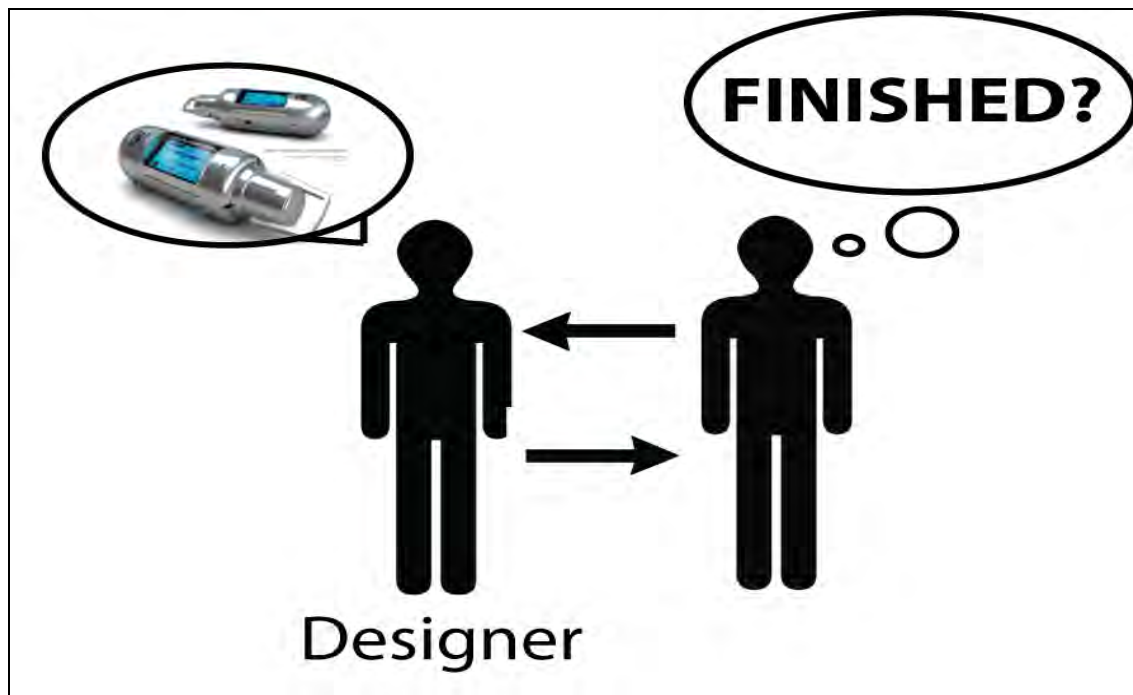


Figure 5.9 The communication of different Level of Commitment to design intent

Higher levels of commitment indicate completion. However this is a characteristic of embodiment that may be unwanted (Pipes 2007). The use of 3D CAD to communicate solution ideas to stakeholders may suggest too high a level of commitment. This may then constrain decision making (ibid). The design tool will influence the level of commitment communicated through the embodiment of design intentions. However, the tool's influence must also be considered in terms of the designer's own

idiosyncratic use of design tools and the wider context of tool use in practice and in the communication of design intent.

Chapter Summary

This Chapter described the identification and synthesis, through literature review, of 5 Universal Tool Characteristics (UTCs): Mode of Communication, Level of Ambiguity, Transformational Ability, Level of Detail and Level of Commitment.

Mode of Communication refers to the ability of the tool to support communication of design intent to other stakeholders and/or reflection-in-action during design activity. Level of Ambiguity refers to how ambiguous design embodiments appear to be through the use of the design tool. Transformational Ability refers to the ability of design activity, through tool use, to move from one idea to a variation of the same idea (vertical transformations), or from one idea to a new idea (lateral transformations). Level of Detail indicates the amount of detail communicated through the use of a given design tool. Level of Commitment refers to the tool's ability to support the embodiment of design intent that appears to be more or less committed.

The 5 identified UTCs were used as a means to investigate designer attitudes towards the design tools identified in the Taxonomy (Chapter 4). In this way, the use of the UTCs was seen as a comprehensive reflection of an extensive literature on the use of design tools. Although not representing a definitive or prescriptive means to describe the character of design activity and tool use, the 5 UTCs were considered sufficient to assess designer attitudes towards design tools. The UTCs, along with the 10 tools classified within the Taxonomy, informed the research strategy described in the following Chapter (Chapter 6).

Chapter 6: Research Methods

Introduction

This Chapter presents the research methods employed during an empirical investigation of design tools and their use. Two studies were undertaken:

1. A survey study investigated designer attitudes towards tool use (Chapter 7).
2. A subsequent interview study further explored attitudes towards tool use through an approach that used semi-structured interviews to gather qualitative data (Chapter 8).

The survey and interview studies employed the Model of Design Activity and Tool Use (Chapter 3); Taxonomy of design tools (Chapter 4) and Universal Tool Characteristics (Chapter 5). The Model of Design Activity and Tool Use was used as a framework to attempt to relate findings to the various influences presented in the model. The taxonomy of design tools was employed as a means to identify the various design tools to be used in the survey and interview studies. The UTCs were used as a means to measure designer attitudes towards the design tools. The aim was to provide data to address the research questions below and presented in Chapter 1:

The research methodology was by no means a definitive or prescriptive approach to the study of design tool use. The researcher recognises the limitations of these methods as their design was informed by the use of the model of activity and tool use, taxonomy and UTCs. However, their use provided boundaries within which the complex activity of design tool use could be explored.

6.1 Research Questions

The investigation sort to develop understanding of design tool use during practice. To do this four research questions were identified as a means to direct an investigation of tool use during design activity (see also Chapter 1).

1. What are the pre-existing principles, influences and conventions that inform understanding of design tool use in the embodiment of design intent during studio practice?
2. How might knowledge of existing principles be further investigated and what emergent understanding may be gained through this investigation?
3. What might this emergent understanding tell us of the practitioner's attitudes towards and use of design tools during studio practice?
4. How might research findings be best communicated to practicing designers to foster a more critical engagement with design tools?

A review of literature resulted in a number of secondary research outcomes that would inform research methods. These outcomes are summarised below:

- The industrial design process was described as a having 3 stages: concept, development and detail design (Chapter 3).
- A Model of Design Activity and Tool Use was adapted from activity theory (Chapter 3).
- A taxonomy of design tools was constructed based upon the 3 stage approach to practice (Chapter 4)
- The affording implicit character of design tools of embodiment were described through a set of UTCs (Chapter 5).

The aim of the research was to gather data to explore designer attitudes towards tool use and develop understanding of the ideas, principles and conventions that underpin use during the design process. This understanding was then employed as a means to

support designers in their engagement with design tools during practice (IDsite, Appendix O).

6.2 Research Methods: Context and justification

Design research is concerned with creating knowledge about design through an investigation into the design practitioner, the design processes through which the practitioner works, and the product outcomes of that process (Cross 1999). This research was concerned with the investigation of design tools during design activity.

A number of research strategies are employed in design research: philosophical analysis; case studies; interviews and surveys; protocol analysis and observation studies. More recently, 'practice-based' and 'practice-lead' design research has emerged as a means of enquiry. In a study by Pedgley (2007), the authors own design activity was employed as a research method for generating case study data on the industrial designer's decisions on material selection and processes. In Pedgley's (ibid) study, design diaries were employed to describe the day's design activity which were then synthesised and coded to investigate reasoning behind the industrial designer's choice and use of materials. Protocol analysis has also been employed during design research to investigate process. Most notably, Cross et al (Cross & Christiaans et al. 1996) conducted a series of protocols at TU Delft, which investigated design activity as a creative process of ideation. Jiang's et al's (2009) study indicated the wide use of this research method.

Although the observation of activity through case study and protocol analysis can provide insight into design activity (Cross & Christiaans et al. 1996), these methods are less well suited to research aiming at studying the underlying reasons for design tool use. The researcher wished to employ a strategy that would provide data on the attitudes designers hold towards the tools they use. Romer and Pache (2001) argue that observation does not afford the kind of understanding required to develop knowledge of the individual's thinking behind tool appropriation and use, 'simply observing users does not tell the researcher enough; it must be discovered what the user is thinking'. Malone (In Nardi 2001 p7) notes that, 'behaviour cannot be understood without reference to intentionality...The observer sees the same behaviour but cannot know what it means without asking the user.' Engestrom et al (1999) makes this point by suggests that a focus of observation on activity will result in understanding of problem solving processes, as discussed in Cross' et al's protocol studies (Cross &

Christiaans et al. 1996), but not of the motivations behind that activity (Engestrom, Op cit). Nelson & Stolterman (ibid, p.165) consider that experiment and observation may not be entirely appropriate to the study of design: 'principles of observation cannot transcend their own context and become an epistemological link to other frames of reference'. An investigation based upon observational case study analysis may tell us how a practitioner uses tools in the embodiment of design intent, but may tell us less about why a particular tool is employed in a given situation. For these reasons observing tool use during practice was considered unsuitable. Moreover, practice-based research may be effective in understanding relationships between designer and tool use from the perspective of one individual, but may tell us less of how skills and experience, working methods, habits and beliefs influence design activity.

The survey was employed as a research strategy to capture designer attitudes towards tool use. In a survey study to explore the use of computer tools at the front end of design practice, Romer and Pache et al (2001) undertook a postal survey of 106 designers. The results were then used as evidence to compare the use of conventional sketching methods against an increasing use of CAD, 'In this investigation 200 questionnaires were posted to German-speaking designers' (ibid p479). Miranda et al's (2007) paper, 'The development of a design behaviour questionnaire for multidisciplinary teams' employed a survey in order to test the behaviour of the design team members. Other examples of survey use in design research include Robertson and Radcliffe (2009) survey to justify a case study concerned with the impact of CAD tools on creative problem solving in engineering design; Robertson (ibid) evaluation of the transferability of phenomena to other people and other contexts; Huang's et al (2007), investigation of consumer annoyance in the operation of digital products; Lam's et al. (2005) investigation into the contribution of designers to improvement in the construction and manufacture of the design outcome and Melle's (2010) survey to gather information from design academics, educators and students.

The survey approach can be problematic. Robson (1993), in discussing relationships between responses to attitude surveys, suggested disparity between how the subject described their attitudes towards an activity and the individual's actual actions. However, the survey was followed by a study employing semi-structured interviews to further explore survey findings related to designer attitudes towards tool use.

The interview is a method to generate qualitative responses to help answer research aims. Within design studies, the interview as research method is well established

(Robertson & Radcliffe, Miranda et al. 2007, Argument et al. 1998, Pei et al 2008). Three types of interview are available to the social sciences researcher: fully structured, semi-structured, and unstructured (Robson 1993). The structured interview, much like the questionnaire, employs closed questions to gather response that are then recorded on a standardised schedule (ibid). Semi-structured interviews employ questions that have been worked-out in advanced and address a specific topic of enquiry but leave room for leeway in response. Open-question types are used to provide opportunity to discuss questions in full. Often, an interview guide will be used but with flexibility to give the respondent room for embellishment. Finally, the unstructured interview describes an approach where the interviewer has an area of interest in mind but then allows the conversation to develop (Robson 1993). The researcher used the semi-structured approach to interview to explore in greater detail emergent themes within the survey study.

6.3 Informing Research Methods: Activity Theory, Taxonomy & UTCs

In Chapter 3 an adapted model of activity theory (Engestom et al. 1999), was presented as a means to describe the various principles informing tool use during design practice. The aim of the research was to develop understanding of how the principles within the model interact to inform tool use. The model of tool use in practice underpinned the investigation of design tools in terms of the relationships suggested by the model and was used as a framework to explore the survey and interview data (Chapters 7 and 8). It is accepted that an investigation of tool use in terms of the principles presented in the model frame such an investigation within the boundaries of the model, and that this will influence the analysis and interpretation of the data. However, the study of tool use in practice is both rich and complex (Stolterman et al. 2008, Visser 2002). The model provided one approach to the investigation of this complexity.

The taxonomy of design tools (Chapter 4) and UTCs (Chapter 5) were employed in the design of survey and interview questions (see 6.4.4 Survey Design & Process & 6.5.2 Interview Design & Process). In summary, the taxonomy provided a description of the 10 design tools most often used in support of design activity, which were then used within the survey and interview studies. The 5 UTCs (Chapter 5) were employed as a means through which designer attitudes towards the character of the 10 design tools were investigated.

The UTCs and taxonomy of design tools were seen as vehicles through which data on attitudes towards tool use could be collected. However, this investigation was also limited to the tools identified in the taxonomy, and the exploration of attitudes limited to measuring designer responses in terms of the 5 UTCs. The interview study, through the use of open question types (Robson 1998) suffered less from these restrictions as interviewees were given an opportunity to suggest the tools they used and the reasons for their use at a given stage in the design process.

6.4 Survey Study

The objective of the survey was to generate data on the attitudes designers hold towards the use of various design tools during design practice, as work progressed from concept, through development and on to detail design. This data was then employed to consider what it might tell us of tool use and how use relates to the various principles indicated in the Model of Design Activity and Tool Use (Chapter 3).

6.4.1 Survey Samples

The survey was used to explore attitudes towards tool use from two distinct groups. A first sample was drawn from practicing designers employed within design consultancies of different sizes. A second survey was taken from a sample of 3rd year and graduating design students. It was hoped that a comparison between these two groups would indicate how experience and working background influences attitudes towards design tool use.

The Dreyfus and Dreyfus (1986) model of skills acquisition in the transition from novice to masterful states was employed to classify designers within the samples. The Dreyfus model describes the practitioner's progress through experience of practice using levels of expertise running from 'novice' to 'visionary'. Using the Dreyfus and Dreyfus model (Op cit), survey samples were sort from designers that could be described as 'advanced beginners' (Students) and those that the Dreyfus model describes as 'competent' and 'expert' (practicing designers). Of course individuals will vary in their experience and expertise, but the Dreyfus model served as a useful means of discriminating between the different levels of expertise the two samples brought to their use of design tools. This was then employed to identify and consider different approaches to design activity and tool use (Chapter 7).

6.4.2 Practitioner Sample

The practitioner sample was identified through the use of two design directories: the Core77 Industrial Design Magazine designer directory (Core77 Online Industrial Design Magazine 2010) and The Directory of Product Design Consultants (The Directory of Design Consultants 2009). Core77 is an online magazine and hub for practitioners to explore and discuss issues relating to contemporary industrial design practice, ‘a gathering point for designers and enthusiasts alike by producing design competitions, lecture series, parties, and exhibits.’ (Core77 Online Industrial Design Magazine 2010). The Directory of Product Design Consultants is a web-based directory used by consultancies to list their business details. A Google search of ‘industrial design directory’ puts The Directory of Product Design Consultants top followed by Core77 as the next directory listed (search conducted 21/09/2009).

Search engines within these two directories were utilised to identify design consultancies that used the terms ‘industrial’ and/or ‘product’ to describe their design discipline. Invitations to complete an online survey were sent to those designers within these categories. A covering email was sent outlining the aims of the study with an embedded link to an online survey.

The survey of design practitioners received 116 responses. Initial survey questions were designed to gather data on practitioner attributes. Table 3 shows results for the survey question asking practitioners about the discipline within which they worked:

Design Discipline	Number of Respondents
Industrial Design	55
Product Design	37
Engineering Design	6
Packaging Design	2
Design Management	2
Automotive/Transportation Design	2
Interior Design	2
Interaction Design	2
Graphic Design	1
Other	4
*Fail to provide a response to question	3

Total Responses: 116

Table 3 The design discipline for which you work

Despite restricting search terms to 'Industrial' and 'product' design, a small number of respondents considered themselves graphic (1), interior (2) or interaction designers (2). A further 2 respondents described themselves as design management, 2 more as packaging designers and 6 as Engineering designers. Being that all these respondents also describe themselves as working within 'industrial' or 'product', a decision was made not to exclude results from these practitioners in the analysis of findings. 3 respondents fail to complete attribute questions.

A further survey question asked practitioners of the number of years experience they had working within the above disciplines (Table 4):

Years of Experience	Number of Respondents	Level of Expertise
0-1 Year	1	Advanced beginner
1-3 Years	12	Advanced Beginner/Competent
4-8 Years	18	Competent
9-15 Years	26	Proficient
15 Years or more	55	Expert
*Fail to provide a response	4	N/A
Total Responses: 116		

Table 4 Number of years experience and level of expertise

The largest proportion of the sample responded by indicating 15 years or more experience of practice (55). This was followed by 9-15 years (26), 4-8 years (18), 1-3 (12) and 1-0 years of experience (1). Using the Dreyfus and Dreyfus model (1986) 1 respondent was at an 'advanced beginner' level of experience (0-1 Year). 12 were described as 'advanced beginner/competent' (1-3 Years). A further 18 were described as 'competent' (4-8 Years experience); 26 as 'proficient' (9-15 Years) and 55 (15 Years or more) as 'expert'.

Results indicated the sample of design practitioners had substantially more experience of practice compared to the sample of students and that a majority of the sample described themselves as industrial or product designers.

6.4.3 Student Sample

A paper-based survey, identical to the practitioner's, was taken from a sample of 3rd year and graduating design students. The student survey was conducted in two separate locations at two different times. A survey of graduating design students was conducted over three days at the New Designers Exhibition, Business Design Centre, London between the 11th and 13th of July, 2009. Graduate design exhibitors from courses in industrial, product and transport design were surveyed (See Appendix D and E for copy of graduate survey). The New Designers exhibition provided the researcher with an opportunity to survey graduates across a number of institutions. A total of 62 graduates were surveyed. A second survey was conducted with 3rd year students of industrial design at Loughborough University's Faculty of Design and Technology. Although this meant the Loughborough sample was restricted to the student experience at one institution, this was considered against the need to increase the sample size of 62 collected from the New Designers Exhibition. The benefit of a larger sample size was considered to outweigh limitations in the sample's experience. Table 5 illustrates the location of the two samples, number of students in each sample, title of the students' course of study and level of expertise (Dreyfus and Dreyfus 1986):

Location of Survey	No. of Students	Title of Course	Level of Expertise
New Designers Exhibition 2009	62	Various courses throughout UK using 'Product', 'Industrial', 'Transport' in course title (Graduating)	Advanced beginner
Loughborough University, Faculty of Design and Technology	44	BA (Hons) In Industrial Design (3 rd Year)	Advanced Beginner
Total Student Sample: 106			

Table 5 Sample of design students

A further sample of 44 3rd year undergraduate students was taken at Loughborough University, making a total sample size of 106 3rd year and graduating design students. This compared to the sample of 116 practitioners.

6.4.4 Survey Design & Process

A survey employing closed Likert scale questions (Robson 1993, Bryman 2008, De Vaus 1996) was used to gather data on designer attitudes towards design tools. An

online survey¹² was used to gather practitioner responses (Appendix A to C). This was followed by an identical paper-based survey of student designers (Appendix D & E).

An advantage of using a self-completion survey as an instrument of data collection was its ability to be taken by a large sample size in a relatively short space of time. However, as the respondents had to read and answer each question themselves, the design and layout of the survey was particularly significant (Bryman 2008 p217). The researcher considered three factors when designing the self-completion survey:

- Have fewer open questions, since closed ones tend to be easier to answer
- Have an easy to follow design to minimise the risk that respondents will fail to understand or follow questions
- Be shorter to reduce the risk of respondent fatigue

On the front page of the on-line practitioner survey respondents were provided with a brief description of the aims of the research and made aware of Kingston University’s ethical code of conduct. They were then informed that information provided would be used in confidence and that their identity would not be disclosed.

The practitioners were asked a series of closed questions to gather data on the designers working environment, education, the design discipline within which the practitioners worked and the number of years experience within practice. Table 6 shows the four attribute questions asked and the response items available within each question. Practitioners were asked to choose one response per question:

Attribute Questions	Response Items
Q. How would you describe the size of the company/consultancy you work in?	Larger Corporate Organisation Larger consultancy (20+ people) Mid-sized consultancy (10-20 people) Smaller consultancy (9 people or less) One or two person practice Other
Q. What is your highest qualification?	HND/HNC Bachelors degree Masters degree PhD None of the above
Q. How would you describe the design	Industrial design

¹² Survey Methods is an online toolkit for survey design and implementation which allows the researcher to conduct a questionnaire through a link to the survey that may be embedded in an email or webpage. Data is then sent back and stored in an online account to be retrieved and analysed at a later date.

discipline in which you work? Please choose the one closest answer:	Product design
	Automotive/Transport design
	Packaging design
	Engineering design
	Interaction design
	Interior design
	Graphic design
Q. For how long have you worked in the above profession?	Other
	0-1 Year
	1-3 Years
	4-8 Years
	9-15 Years
	15 Years or more

Table 6 Attribute question used in online survey of design practitioners

As the practitioner survey was self-complete the questions in Table 6 were used to gather data on the practitioners' background. This was unnecessary for the student sample as the researcher had prior knowledge of the students' level of experience and background as 3rd year undergraduate and graduating designers.

Following this first section on the practitioner survey (Appendix A - C) and at the start of the student survey (Appendix D & E), the 10 tools identified in the taxonomy of tools (Chapter 4) were used in the design of the Likert-scale (Robson 1993) survey questions. Figure 6.1 illustrates the 10 design tools used as they appear in the taxonomy:

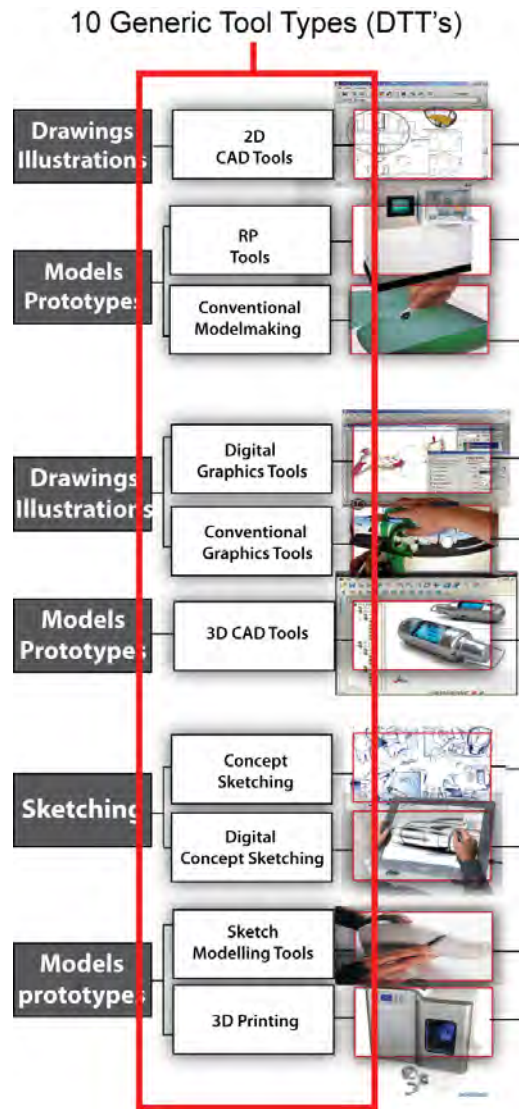


Figure 6.1 Section of taxonomy showing ten design tools used in the surveys

The design of Likert-scale questions was informed by the UTCs identified in Chapter 5. Table 7 presents the 8 Likert-scale questions asked in both the on-line practitioner survey and the identical, paper-based student survey. The left column presents the questions as they appeared in both surveys (Appendix A - E). The column to the right indicates the UTC each question was designed to measure:

8 Questions to measure 5 Universal Tool Characteristics (UTC's)	UTC's Measured
<p>Q. The design tools listed below are useful for: Representing the engineering detail of design ideas: Do you agree or disagree?</p>	<p>UTC: Level of Detail To what extent the design tool affords a high or low level of specific detail.</p>

Q. The design tools listed below are useful for: Representing the artistic/creative form (less detail) of design ideas: Do you agree or disagree?	UTC: Level of Detail To what extent the design tool affords an overall or artistic impression of detail.
Q. The design tools listed below are useful for: Representing design ideas in a more constrained, unambiguous way: Do you agree or disagree?	UTC: Level of Ambiguity To what extent the design tool affords design ideas to be represented unambiguously
Q. The design tools below are most useful for: Design work that can move easily between design ideas (Lateral Transformations): Do you agree or disagree?	UTC: Transformational Ability To what extent the design tool affords movement from one design idea to a new idea – horizontal transformations.
Q. The design tools below are most useful for: Design work on variations of one or the same design idea (Vertical Transformations): Do you agree or disagree?	UTC: Transformational Ability To what extent the design tool affords movement from one idea to a variation of the same idea – vertical transformations
Q. The design tools below: Communicate a high Level of Commitment to design ideas: Do you agree or disagree?	Level of Commitment How the design tool communicates a high or low Level of Commitment to design ideas.
Q. The design tools below are more useful for: Communicating design intentions to others: Do you agree or disagree?	Mode of Communication How the design tool affords communication of design ideas to others.
Q. The design tools below: Aid reflection and the dynamic generation and evolution of design ideas: Do you agree or disagree?	Mode of Communication How the design tool affords self-reflection-in-action and the emergence of design ideas

Table 7 8 Likert scale survey questions and universal tool characteristics measured

Responses to the 8 questions were registered using five item Likert-scales (Robson 1993), whereby the following response values were given:

Strongly Agree (+2); Agree (+1); Neutral (0); Disagree (-1); strongly Disagree (-2)

The 8 questions were asked in relation to each of the 10 design tools included in the two surveys making a total of 80 questions relating to designer attitudes towards design tool use in each completed questionnaire. The online survey of design practitioners captured responses through a matrix of check-box questions (Appendix A - C). In the case of the paper-based student survey, respondents marked their response next to the corresponding item on each Likert-scale question (Appendix D - E)

At the end of the practitioners' survey, a single open-ended question was provided as an opportunity to provide further responses:

- Is there anything you would like to add? Please use this space to add any suggestions, observations or criticism of the questionnaire, research, its aims and objectives:

6.4.5 Survey Data Coding and Analysis

In both the practitioner survey and the survey of design students, responses to the 8 Likert-scale questions were coded in order to analyse the data. The Likert-scale questions each had 5 items. These items were assigned response values ranging from +2 to -2. All response values registered using the Likert-scales for both practitioner and student surveys were exported to Microsoft Excel where spreadsheets were created for each of the practitioner and student surveys.

Coded responses were arranged in columns within the spreadsheets. Each column represented the total responses to a single Likert-scale question as it related to one design tool. The database of spreadsheets consisted of 160 columns of raw data (8 columns for each of the 10 design tools, a total of 80 for the sample of practitioners and a further 80 for the student sample). Each row presented a single response from the practitioner or student respondent. The coded responses within each column were then arranged in descending numerical order from +2 to -2. A mean score was calculated for each of the 160 columns of data (the sum total for each column divided by number of respondents). These mean scores were then used in the presentation of results (Chapter 7). For each of the 160 columns, the total number of responses to each of the 5 items of the Likert scale was also calculated. These totals were then used to calculate responses across the 5 items of each Likert-scale as percentages of the total response to each Likert-scale question (number of responses to each item divided by number of respondents). These percentages were also used in the presentation of survey results (Chapter 7).

6.4.6 Pilot Survey: Non-response and Respondent Fatigue

The survey of design students achieve a 100% return rate. This can be explained because respondents were approached individually during the survey administered at the New Designers exhibition. The survey of 3rd year students was also performed through a hand-out to the 3rd year cohort. The completed surveys were then returned. The online survey of practitioners, however, suffered from non-response. In contrast to

the student sample, the practitioner survey achieved a response rate of approximately 20%. It may also have been that those practitioners that did respond had a particular interest in the subject (the use of design tools), which biased the sample group (Bran, Op cit, p.169).

Before the full survey of design practitioners and students was conducted, a pilot was employed to evaluate the survey's design (De Vaus 1996). The pilot was sent to 20 design consultancies identified through the Core77 design directory. After receiving only 2 responses the researcher contacted the consultancies, resulting in the identification of surveys length and the repetitive nature of the questions as reasons for non-response. To address these concerns the survey's length was reduced through a reduction in the number of Likert-scale questions used to gather attitudes towards design tools from 10 questions to 8.

The survey was also divided into 3 shorter questionnaires (Table 8) reducing the number of Likert-scale questions asked within each survey (see Appendix A - C). Table 8 illustrates the breakdown of the 8 Likert-scale survey questions within the 3 shorter questionnaires: The column to the left shows the 3 shorter questionnaires. The centre column identifies the practitioner attitudes each questionnaire was designed to measure in terms of UTCs (Chapter 5). The column on the right indicates the questions included in each questionnaires. For example, the questionnaire for Design Tools: Design Embodiment asked practitioners about their attitudes towards 10 design tools through 3 Likert-scale questions relating to Level of Detail and Level of Ambiguity:

Survey	UTC's Measured	Survey Questions Asked: The design tools listed below are useful for:
Design Tools: Design embodiment (Appendix B)	Level of Detail Level of Ambiguity	Representing the engineering detail of design ideas: Do you agree or disagree? Representing the artistic/creative form of design ideas. Do you agree or disagree? Representing design ideas in a more constrained unambiguous way. Do you agree or disagree?

<p>Design Tools: Transformation (Appendix A)</p>	<p>Transformational Ability</p>	<p>Work that moves from one design idea to a <i>new</i> design idea (lateral transformation). Do you agree or disagree?</p> <p>Work on variations of one or the same design idea (vertical transformations). Do you agree or disagree?</p>
<p>Design Tools: Communication (Appendix C)</p>	<p>Level of Commitment</p> <p>Mode of Communication</p>	<p>Communicate a high Level of Commitment to design ideas: Do you agree or disagree?</p> <p>Communicating design intentions to others: Do you agree or disagree?</p> <p>Aiding reflection and the dynamic generation and evolution of design ideas: Do you agree or disagree?</p>

Table 8.3 smaller surveys and UTC's measured by each and questions asked

In the survey of design students, 10 prompt cards were designed to gather information on designer attitudes towards design tools, One card for each of the 10 tools included in the survey (Appendix D & E). Figure 6.2 illustrates the card relating to the design tool 3D CAD. In an identical manner to the practitioner survey, the students were required to answer the 8 Likert-scale questions, indicating their attitudes towards each of the design tools illustrated on the 10 prompt cards:

Supporting card for question 8

Design Research Centre
Kingston University London
Email: K0729860@kingston.ac.uk



Design Tool 7: 3D CAD TOOLS

Q8. This question asks for your opinion of 3D CAD.

3D CAD Tools

For example:

- Autodesk Maya/3ds Max des
- Rhinoceros Nurbs modeller
- Solidworks Premium
- Solidthinking

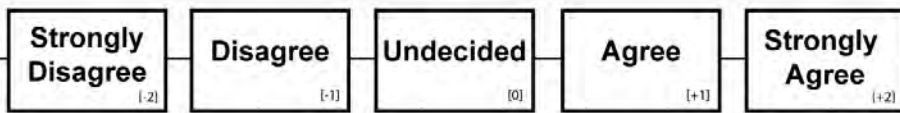
Semi-structured development design

3D CAD Representation

For example:

- Design development Models
- Presentation Models

Semi-structured development design



Q8. Please say to what extent you disagree or agree with the following 8 statements about your use of 3D CAD. (3D CAD TOOLS helps you to)

- 1, Represent the engineering detail of design ideas
2. Represent the artistic/creative form of ideas
3. Represent design ideas in an unambiguous way
4. Move easily from one idea to another idea
5. Focus on variations of the same design idea
6. Communicate a high level of commitment to design ideas
7. Clearly communicate design intentions to others
8. Reflect upon and quickly generate new design ideas

Figure 6.2 Prompt card used in survey of graduates to support understanding of terms

The prompt card above illustrates the design tool 3D CAD and the kinds of design embodiments made through its use. Below this, a Likert scale is presented as 5 large white boxes. 8 questions relating to designer attitudes towards the UTCs of 3D CAD tools are contained within a grey box at the bottom of the card. The researcher's recorded responses to each of the 8 questions on a separate sheet. 10 cards were

presented in all, one for each design tool identified within the taxonomy and used in the survey.

Using the prompt cards to survey students on their attitudes towards design tools, two problems were identified. Firstly because of the way the survey was conducted as a closed question interview (Robson 1993, De Vaus 1996), each survey took an average of 20 minutes to complete. Secondly, the number of questions meant that some of the graduate participants lost interest (respondent fatigue) as the interview progressed.

To address these issues, the questionnaire, like that used in the sample of practitioners, was divided. Rather than splitting the questionnaire along the lines of the 8 attitude questions, as was the case with the practitioner questionnaires (Table 8 above), the student survey was divided into 2 shorter questionnaires each containing questions relating to 5 of the 10 design tools (Table 9). This division is illustrated in table 6 below (see also Appendix D & E):

Student Survey (Appendix D)	Student Survey (Appendix E)
Conventional Sketching	Digital Sketching Tools
Sketch Model Making	3D Printing Tools
Conventional Graphics Tools	Digital Graphics Tools
Conventional Model Making	3D Digital Modelling Tools
2D CAD Drawing Tools	Rapid Prototyping Tools

Table 9 Graduate survey split into two shorter surveys through division of 10 design tools


The re-design of the prompt cards thus allowed student and graduate designers to mark their answers directly onto the questionnaire sheets (Appendix D & E). Each page in the revised questionnaire related to a single design tool, making each survey 5 pages in length, one page for each tool identified in the taxonomy (Table 9).

Figure 6.3 illustrates a page from the revised student survey asking questions about the design tool '3D CAD'. At the top of the page, 8 Likert-scale questions gather data on attitudes towards 3D CAD tools. As a guide to help the students, image cards from

the first iteration of the questionnaire were used showing, to the left an example of the tool and below this a list of example media employed in the use of 3D CAD. To the right a second card gave an example of the kinds of embodiments made through the use of 3D CAD tools (Figure 6.3):

Digital 4

Design Research Centre
Kingston University London
Email: K0729860@kingston.ac.uk




Design Tool: 3D CAD TOOLS

Q7. Please say to what extent you disagree or agree with the following 8 statements about your use of 3D CAD TOOLS (If you don't use 3D CAD please go to Q8). 3D CAD TOOLS HELP YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>5. Focus on variations of the same design idea</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>2. Represent the artistic/creative form of design ideas</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>6. Communicate a high level of commitment to design ideas</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>3. Represent design ideas in an unambiguous way</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>7. Clearly communicate design intention to others</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>4. Move easily from one design idea to another idea</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p style="text-align: center;"> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>

3D CAD Tools




3D CAD Tools

For example:

- Autodesk Maya/3ds Max des
- Rhinoceros Nurbs modeller
- Solidworks Premium
- Solidthinking

Semi-structured development design

3D CAD Representation



3D CAD Representation

For example:

- Design development Models
- Presentation Models

Semi-structured development design

Q8. Your education provided a good knowledge of the use of design tools and you do not require any more information about them:

Agree Strongly Agree Undecided Disagree Disagree Strongly

Figure 6.3 Example of revised graduate designers survey page

Finally, below these images a further question asked respondents about their education in design tool use during their degree course. These questions were designed to gather data on the influence that the tool had over the graduate's practical work.

This version of the survey was able to address the issues previously identified: the time taken to complete the survey was reduced through self-completion and shorter surveys, thereby increasing the number of completed surveys and reducing completion fatigue. The 2 shorter surveys were distributed in equal amounts to all the exhibitors from courses of industrial and product design. By the end of the field trip, a total of 62 surveys had been completed. Following this, a further round of 44 questionnaires were completed by 3rd year undergraduate industrial design students at Loughborough University making a total sample of 106 3rd year and graduate design students.

Results from the practitioner and student samples were then analysed and considered in terms of the Model of Design Activity and Tool Use (Chapter 3).

6.5 Interview Study

The survey results presented Chapter 7 allowed designer attitudes to be explored through responses to closed questions (Bryman 2008). A limitation of this approach is that data was gathered only in response to the items used in the questions and the respondent is not able to provide reasons or explanations for their responses. In order to explore the reasons for the survey results, open question types were used during an interview study (Appendix F). The open questions provided an opportunity to gather rich data on designer attitudes towards tool use by allowing designers to discuss their use of tools in greater detail.

6.5.1 Sample Group

To help maximise the chances of gathering data from a representative cross-section of the sample frame (industrial and product designers), interviews were sought from practitioners at various stages in their careers. The researcher's personal contacts within industry and at Kingston University were utilised to identify potential interviewees. Individuals were then contacted via email and follow-up calls were made to secure interview dates.

22 requests for interview were sent. Of these, 10 interview dates were successfully arranged. Given the interview study's objective to explore in more depth the attitudes of a discrete sample of designers, rather than (as with the survey study) take a broader sample at one point in time, the sample was considered sufficient in providing opportunities to gather rich responses from practitioners with varying degrees of experience.

The Dreyfus and Dreyfus (1986) model of Stages of Skills Acquisition was again used to classify the designers within the interview sample. Designers with limited experience of practice outside design education were classified as 'Advanced beginners' (0-1 Years experience); those with 1-3 years in practice were categorised as 'Advanced Beginners/Competent'; those with 4-8 years as 'Competent'; those with 9-15 years as 'Proficient' and those with 15 years or more as 'Expert'. Table 10 provides a breakdown of the sample group. The code used to identify each of the interviewees is shown in the left column. Next to this, the practitioner's category of experience is shown. The centre column describes the place of employment: SME, corporate, partnership or in higher education. The column to the right lists job titles as described by the interviewee and finally, the column to the right of this provides the number of years experience:

Designer	Level of Expertise	Type of Employment	Job Title	No. of years experience
Pr01	Expert	SME	Director	15+
Pr02	Competent	SME	Designer	5
Pr04	Proficient	Corporate	Design Manager	11
Pr05	Proficient	SME	Snr Designer	12
Pr06	Expert	Partnership	Co Director	15
Pr07	Competent	SME	Designer	4
St01	Advanced Beginner	Education	Intern	1
St02	Advanced Beginner	Education	Intern	1
St03	Advanced Beginner	Education	Intern	1

Table 10 Attributes of interview sample group

The practitioner interviews were conducted between June to August 2009 and November 2009 to January 2010. The interviews were conducted primarily at the interviewee's place of work or at Kingston University's Knights Park Campus. Interview time and location were at the convenience of the interviewee. On one occasion (Pr02), the researcher contacted an interviewee again after transcribing the interview for a point of clarification. The transcribed interviews were coded and analysed (Chapter 8). After one interview (Pr03, omitted from Table 10), it was found the recording device had failed. As a result, there was no recorded data available for transcription so that Pr03 was removed from the study.

6.5.2 Interview Design & Process

A semi-structured approach to interview was used as the qualitative nature of semi-structured interviews is particularly effective in gathering data based on emotions, experiences and attitudes (Bryman 2008, Robson 1993). The interview study was seen as a strategy through which designer attitudes could be further explored to understand motivations and experiences. The semi-structured interviews used a set of open questions (Appendix F), allowing flexibility in response (Robson 1993). This approach enabled interviewees to speak more widely with an emphasis on the interviewee's elaboration of points of interest (Denscombe 2003).

The researcher used an interview guide to support the interview process (Appendix F). Each interview was recorded for later transcription and analysis using data mining software (see Data Coding and Analysis, 6.6). The interview consisted of a set of 9 open-ended questions (Table 11):

9 Questions Asked at Interview

Q1: Many design academics have used a three stage model to describe the 'problem solving' phase of ID practice. What do you think of this model in terms of your own experience of practice?

Q2: What design tool(s) do you use most during conceptual design work?

Q3: Could you suggest reasons why [XXX] tool(s) are used most during conceptual design work?

Q4: What design tool(s) do you use most during development design work?

Q5: Could you suggest reasons why [XXX] tool(s) are used most during development design work?

Q6: What design tool(s) do you use most during detail design work?

Q7: Could you suggest reasons why [XXX] tool(s) are used most during detail design work?

Q8: In terms of visualization and modeling abilities, what do you look for in a graduate designer's portfolio when considering them for employment in your organisation

Q9: Given the abilities you have suggested, could you say why it is important for a designer to have these abilities?

Table 11 9 Questions asked at interview

The timeframe for the interview was between 30 and 40 minutes which was considered sufficient time to allow the discussion to develop and the designer to warm to the topic, but not too long as to test attention or willingness to participate (Denscombe 2003). The interviews were then recorded, transcribed and coded for analysis using the qualitative data mining software, NVivo (see below).

At the start of each interview the interviewees were made aware of the aims of the enquiry and their ability to terminate the interview at any time. They were also informed that the interview was being conducted in accordance with Kingston University's research ethics guidelines and that their identity and response would remain confidential. The interviewer then proceeded to present the designers with the 3 stage model of industrial design process identified through literature review and used to inform the taxonomy of design tools (Chapter 4). The interviewee was then asked for their response to the model in the context of their experience of studio practice. Figure 6.4 illustrates the model of design process presented at interview (see also Appendix F):

Page 1: Use of design tools

Design Research Centre
Kingston University London
Email: K0729860@kingston.ac.uk

Design Tool use by Industrial Designers

This questionnaire is part of a research programme examining the use of design tools during practice. By 'design tool' we mean the various media and processes through which industrial designers embody and communicate their ideas - Sketching, CAD or RP for example

1. Many design academics have used a three stage model to describe the 'problem solving' phase of ID practice. What do you think of this model in terms of your own practice experience?

Design Process

Design tools used to support design idea visualisation, embodiment and development during design practice

The design process with emphasis on problem solving phase (adapted from Baxster 1995, Cross 2000 and Press et al 2001)

Survey No:

Date

Time:

Figure 6.4 Page 1 of Interview Guide with illustration of design process

Questions 2 asked interviewees to suggest what tool(s) they used during concept design to support their studio practice. Question 3 asked the designers to describe their reasons for using the tools suggested in response to Question 2. This process was then repeated for tools used during development and detail design (Questions 4 to 7, Appendix F and Table 11).

Questions 2-7 were designed to allow the practitioner to speak widely about their use of tools in support of their own design activity. The aim was to facilitate responses to develop understanding of the underlying influences on tool use: stakeholder requirements, individual working methods, influence of process and requirement to communicate: What it was about the tools they used, in the minds of the designers, that made them more or less effective during design practice.

Questions 8 and 9 asked interviewees about the skill-set required of graduate designers in terms of tool use in practice (Table 11). These two final questions also provided a second chance for the interviewee to elaborate on their previous responses to tool use at various stages in the design process.

A recording was made of each interview and transcribed soon after (typically within a week). Over the course of the interview, the researcher prompted the interviewee to try to elicit further conversation. The interviewer also made, after each question, short summaries of the information provided which were used as checks to clarify points of interest and as a way to reinforce the interviewees own comments. All interview data was then coded using data mining software.

6.6 Interview Data Coding and Analysis

The coding of interview data was required in order to more effectively explore the large amount of data generated from the open-ended questions (Bryman 2008). Coding, through the use of data mining software allowed data to be classified and considered more easily (Robson 1993). Coding of interview transcripts was achieved through the use of QRS NVivo qualitative data mining software¹³. The QRS NVivo software was used to support themed analysis as a method for investigating the designers' discussion of tool use in support of design activity (Robson 1993, Denscombe 2003). The themed analysis consists of an approach to coding with the objective of identifying themes within the data (Bryman 2008). These Theme of Discussion were then used to develop understanding of attitudes towards tool use.

Using the NVivo's system of Nodes and the organisation of Nodes into Node Trees, the discussion of tool use was classified through three levels of coding. Figure 6.5

¹³ QRS NVivo: Software designed to aid in the analysis of qualitative data collected through interview and observation. Discussion was coded using tree nodes to allow the researcher to better navigate the data, annotate transcripts and mark connections and relationships between interviewee responses.

illustrates the Node Tree employed in the coding of discussion related to the use of 3D CAD tools:

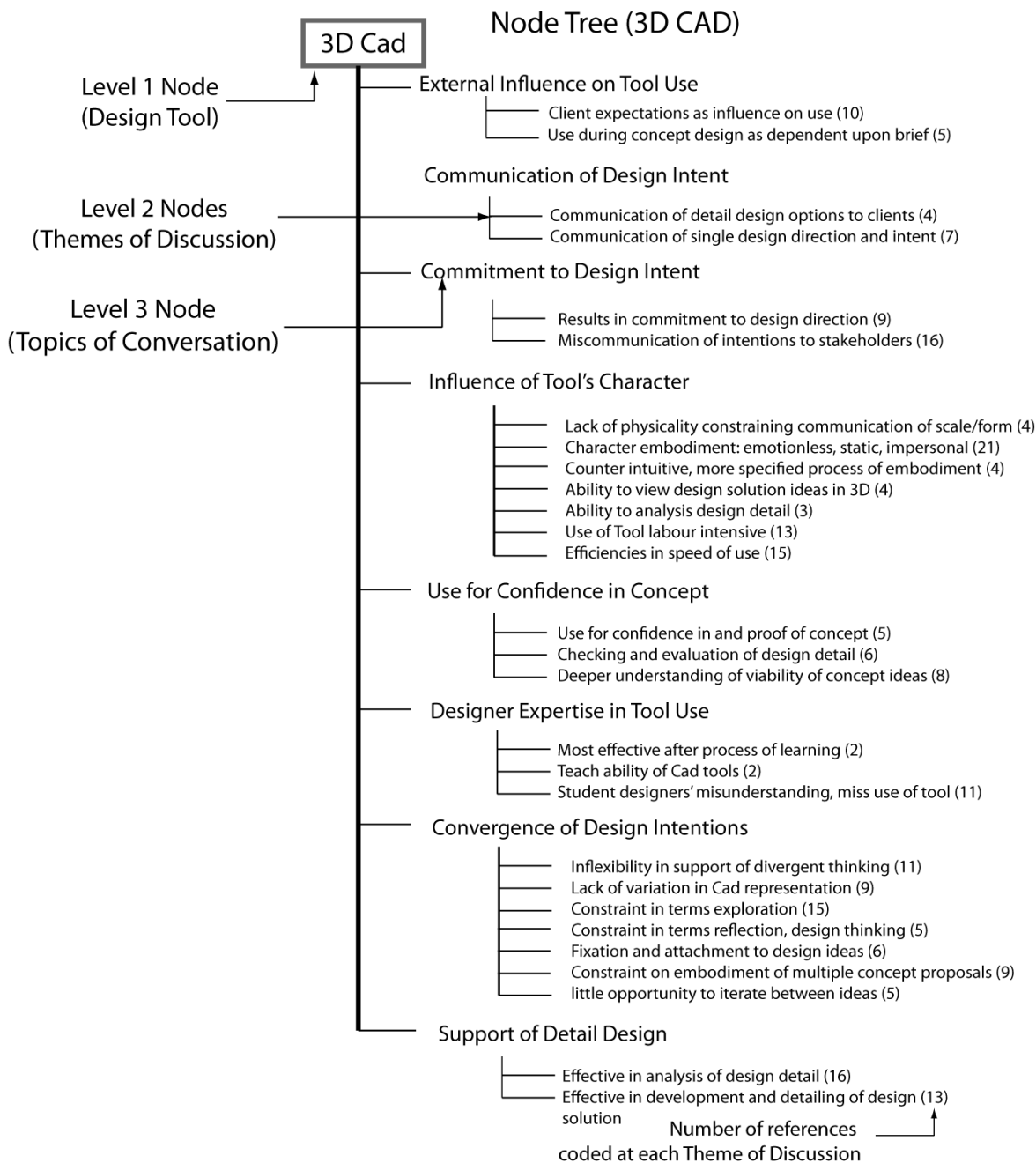


Figure 6.5 NVivo Node Tree for data coded under 3D CAD

Figure 6.6 shows the Node Tree used to classify discussion of hand sketching within the interview transcripts:

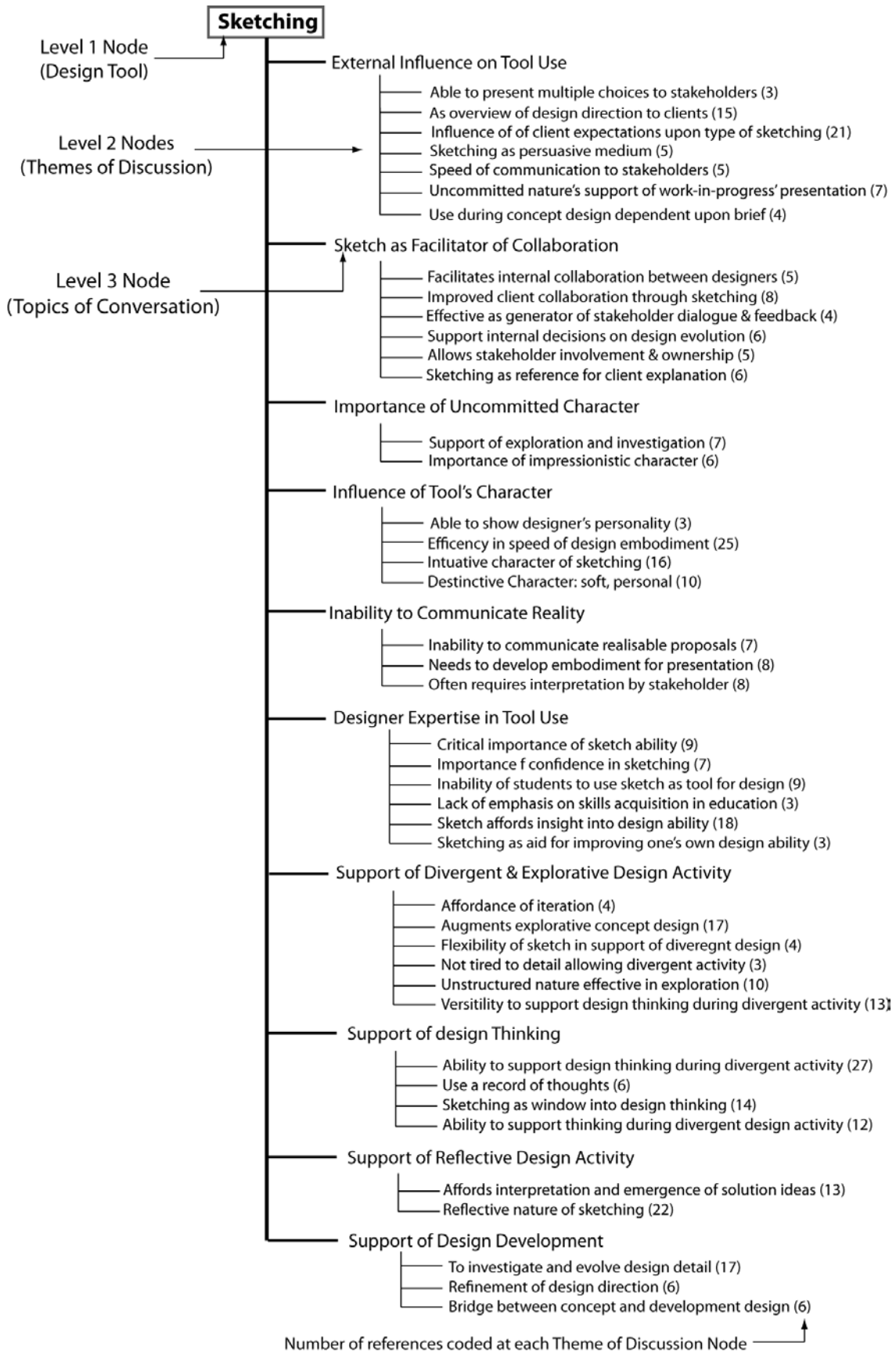


Figure 6.6 NVivo Node Tree for data coded under hand sketching

In order to arrive at the Node Trees illustrated in Figures 6.5 and 6.6, qualitative interview data was explored through three levels of analysis (Figures 6.5 & 6.6).

First level Nodes identified the various design tools discussed by the sample group and the number of reference made to each tool (Level 1 Node, Design Tool Nodes, Table 12). Second level Nodes identified Themes of Discussion within each of the Tool Nodes (Level 2 Node, Figures 6.5 & 6.6). Finally, a third level of coding grouped the Themes of Discussion Nodes within Topic of Conversation to indicate common ideas and thinking across the themes (Level 3 Node, Figures 6.5 & 6.6).

6.6.1 First Level Coding: Design Tool Nodes

A first level of coding identified discussion within interview transcripts relating to individual design tools (Appendix G: interview transcripts). References to individual design tools were identified within the transcripts and classified under the individual Design Tool Nodes. This resulted in 8 Tool Nodes. The study uses the term 'references' to refer to instances of discourse relating to individual design tools. These instances were then classified under the relevant Design Tool Node. Table 12 illustrates the 8 Tool Nodes and the number of references classified under each Node:

Design Tool Nodes	References
3D CAD	299
Hand Sketching	264
RP & 3D Printing	83
Graphics Tools	72
Sketch Modelling	61
Conventional Model Making	50
2D CAD	38
Digital Sketching	28

Table 12 Number of references made to each design tool

The amount of discussion placed within each of the 8 Tool Nodes made clear conversation on design tools was heavily weighted towards 3D CAD and hand sketching (299 and 264 references). Because of the amount of data classified within these two Design Tool Nodes, it was felt that an analysis of these two nodes would provide the best opportunity for exploring designer attitudes towards tool use in greater

detail. As a result, the analysis of interview data was restricted to data within the 3D CAD and hand sketching Tool Nodes.

6.6.2 Second Level Coding: Themes of Discussion Nodes

A second level of coding was applied to the references coded within the Design Tool Nodes hand sketching and 3D CAD. Discussion within these two nodes was re-examined and memos were used to note initial thoughts relating to the designers' critique of the two tools. A final examination of data was then conducted against the memo annotations (Robson 1993). This process resulted in the identification of a number of Themes of Discussion, which related to attitudes towards the two tools. The Theme of Discussion did not necessarily relate to the previously identified UTCs (Chapter 5) or principles within the Model of Design Activity and Tool Use (Chapter 3). Instead the researcher explored the data for any emergent themes, rather than restrict exploration to the UTCs, although Themes of Discussion relating to UTCs did emerge (Chapter 8). Table 13 presents the 28 Themes of Discussion Nodes used in the classification of the 299 references to 3D CAD:

28 Themes of Discussion Nodes Relating to 3D CAD	
1. Use for confidence in and proof of concept	15. Ability to view in 3D
2. Evaluation of design detail	16. Ability to analyse design detail
3. Understanding and viability of concept ideas	17. Use of tool Labour intensive
4. Inflexibility in support of divergent thinking	18. Efficiency in speed of use
5. Lack of variation in CAD embodiment	19. Effective in analysis of design detail
6. Constraints in terms exploration	20. Effective in development and detailing of solution ideas
7. Fixation and attachment to design ideas	21. Communication of detailed proposals to stakeholders
8. Constraints in terms of reflection	22. Communication of single design direction
9. Constraint embodiment of multipul concept proposals	23. Most effective after process of learning
10. Results in commitment to design direction	24. Teachability of CAD tools
11. Misscommunication of intentions to stakeholders	25. Student designer's misuse of tool
12. Lake of phisicallity constraint upon communication of form, scale	26. Client expectation as influence on use
13. Character of embodiment: defined, static	27. Use during concept design depenn brief

14.Counter intuitive process of embodiment	28.Little opportunity to iterate
--	----------------------------------

Table 13 28 Themes of Discussion Nodes identified within interview data coded under Tool Node 3D CAD

Table 14 presents the 42 Themes of Discussion Nodes used to classify the 264 references within the Design Tool Node Hand Sketching:

42 Themes of Discussion Nodes Relating to Hand Sketching	
1.Present multipul choice to stakeholders	22.Requires interpretation by stakeholders
2.Overview of design direction to client	23.Critical importance of sketch ability
3.Influence of client expectation on type of sketch	24.Importance of confidence in sketching
4.Sketch as persuasive medium	25.Inability of students to use sketch as design tool
5.Speed of communication to stakeholders	26.Lack of emphasis on skill acquisition
6.Uncommitted nature support work in progress	27.Sketch affords insight into design ability
7.Use in concept design dependent upon brief	28.Sketching's ability to improve own design ability
8.Facilitator of collaboration between designers	29.Affordance of iteration
9.Improved client collaboration through sketching	30.Affordance of explorative concept design
10.Effective as generator of skakeholder dialogue & feedback	31.Flexibility of sketch in affordance of divergent thinking
11.Support internal decisions on design direction	32.Untied to detail allowing divergent thought
12.allow stakeholder involvement & ownership	33.Unstructured nature effective in exploration
13. Sketching as reference for client explanantion	34.Versitility in generation of multiple concepts
14. Supports exploration	35.Ability to support design thinking through divergent activity
15.Importance of impressionistic character	36.Record of thoughts
16.Able to show designer's personality	37.As window into design thinking
17.Efficiency in speed of design embodiment	38.Affords interpretation and emergence
18.Intuative character of sketch	39.Reference to reflective nature of sketch
19.Distinct character: rough, personal	40. Investigate and evolve design detail
20.Inability to communicate realisable proposals	41.refinement of design direction
21.Need to develop embodiment for	42.Bridge between concept and development

presentation

design

Table 14 42 Theme of Discussion Nodes identified within references to hand sketching

6.6.3 Third Level Coding: Topics of Conversation Nodes

In order to effectively use the large amount of qualitative data gathered, it was important to simplify the data through further analysis and classification (Bryman 2008). The 28 and 42 Themes of Discussion Nodes containing references to 3D CAD and hand sketching were re-examined to explore commonality between Themes of Discussion. This commonality was then used to group themes under third level Nodes termed Topics of Conversation. Table 15 illustrates the classification of 28 Theme Nodes (3D CAD) under 8 Topic of Conversation Nodes:

8 3D CAD Topics of Conversation Nodes	28 3D CAD Theme Nodes Classified within Topic Nodes
1. External Influence upon Tool Use	Client Expectations as influence upon use
	Use during concept design dependent on brief
2. Communication of Design Intent	Communication of detailed proposals to clients
	Communication of single design direction
3. Commitment to Design Intent	Use results in commitment to design direction
	Miscommunication of intent to stakeholders; overcommitted
4. Influence of CAD's Character	Lack of physicality constraining communication of scale
	Character of embodiment: static, defined
	Counter intuitive process of embodiment
	Ability to view embodiment in 3D
	Ability to analysis design detail
	Use of tool labour intensive
	Efficiencies of speed
5. CAD's use for Confidence in Concept Ideas	Use for proof of concept proposals
	Checking and evaluating design details
	Deeper understanding of viability of concept ideas
6. Influence of Designer Expertise	CAD most effective after process of learning
	Teachability of CAD tools
	Student designers' misunderstanding/misuse of tool
7. Convergence of Design Intentions	Inflexibility in support of divergent design activity
	Lack of variation in CAD embodiments

	Constraining in terms of exploration
	Constraining in terms more reflective design thinking
	Fixation and attachment to concept ideas
	Constraint on embodiment of multiple concept ideas
	Less opportunity to iterate between ideas
	Little opportunity to iterate
8.Support of Detail Design	Effective in analysis of detail design
	Effective in development and detailing of design proposals

Table 15 Classification of 28 Theme Nodes relating to 3D CAD under 8 Topic of Conversation Nodes

Table 16 illustrates the 42 Themes of Discussion Nodes classified under 10 Topic of Conversation Nodes relating to hand sketching:

10 hand sketching Topics of Conversation Nodes	42 hand sketching Theme Nodes Classified within Topic Nodes
1.External Influence upon Tool Use	Able to present multiple choices to stakeholders
	As overview of design direction to client
	Influence of client expectations upon type of sketch
	Sketching as persuasive medium
	Speed of communication to stake holders
	Uncommitted nature supports work-in-progress embodiment
	Use of sketching during concept design dependent upon brief
2.Sketch as Facilitator of Collaboration	Facilitates internal collaboration between designers
	Improved client collaboration through sketching
	Effective as generator of stakeholder dialogue & feedback
	Support internal decisions on design direction
	Allows stakeholder involvement & ownership
	Sketching as reference for client explanation
3.Importance of uncommitted Character	Supports exploration and investigation
	Importance of impressionistic character
4.Influence of Tool's Character	Able to show designer's personality
	Efficiency in speed of design embodiment
	Intuitive character of sketching

	Distinctive character: soft, personal
5.Inability to Communicate reality	Inability to communicate realisable design proposals
	Needs to develop embodiment for presentation
	Often requires interpretation by stakeholders
6.Designer Expertise & Competence in Use	Critical importance of sketch ability
	Importance of confidence in sketching
	Lack of ability of students to use sketch as tool for design
	Lack of emphasis on skills acquisition in education
	Sketch affords insight into design ability
	Sketching as aid for improving one's own design ability
7.Support of Divergent & Explorative Design Activity	Affordance of iterations
	Augments explorative concept design
	Flexibility of sketch in supporting divergent design activity
	Untied to detail allowing divergent activity
	Unstructured nature effective in exploration
	Versatility in generation of multiple proposals
8.Support of Design Thinking	Ability to support design thinking during divergent activity
	Use as record of thoughts
	Sketching as window into design thinking
	Ability to support thinking during divergent design activity
9.Support of Reflective Design Activity	Affords interpretation and emergence of solution ideas
	Reflective nature of sketching
10.Support of Design development	To investigate and evolve design detail
	Refinement of design direction
	Bridge between concept and development design
	Affords interpretation and emergence of solution ideas
	Reflective nature of sketching

Table 16 Classification of 42 Themes of Discussion Nodes relating to hand sketching under 10 Topic of Conversation Nodes

The Process of Coding through the Nvivo software allowed qualitative responses to be classified for analysis. In Chapter 8, results of the interview study, this system of coding is used in the presentation and discussion of findings.

Chapter Summary

The Chapter described the synthesis of previously identified principles relating to tool use in practice (Model of Design Activity and Tool Use, Chapter 3; Taxonomy of Tools, Chapter 4 and UTCs, Chapter 5). The synthesis of these principles constituted a framework to explore designer attitudes towards their use of design tools. The framework was applied to the design of an online survey (survey of design practitioners), a paper-based survey (survey of design students) and the design of interview questions and an Interview Guide (interview study). The application of the framework provided examples of how existing knowledge of design tool use (Model of Design Activity and Tool Use, Taxonomy of Tools and UTCs) may be used to inform the design of research instruments (Online Survey, Survey Prompt Card, Interview Guides). These were then employed to explore the use of design tools during practice through a survey (Chapter 7) and an interview study (Chapter 8). The survey study aimed to gather quantitative data to indicate trends; an interview study further explored attitudes through qualitative responses. The combination of survey and interview methods was seen as an approach which would provide a robust opportunity to gather data on attitudes towards tool use.

The use of the framework in the design of survey and interview methods is one approach that may have been taken. However it was seen as an informed strategy grounded by some of the principles and narratives that inform contemporary understanding of tool use in support of design practice.

Chapter 7: Survey Results

Introduction

This Chapter presents results from a survey of 116 practicing designers (Appendix A - C) and 106 3rd year and graduating students (Appendix D - E). The surveys were conducted at the New Designers' Exhibition 2009, Loughborough University's Department of Design and Technology and as an online survey sent to design practitioners at their pace of work (see research methods, Chapter 6). The survey's design was informed by the taxonomy of design tools (Chapter 4) and UTCs (Chapter 5).

Survey results are presented in three sections to explore the relationships indicated in the Model of Design Activity and Tool Use (Chapter 3). A first section presents results relating to each of the 10 tools in the order in which they appear within the taxonomy (those identified as used most often during concept design, through development, to those used for detail design). In this first section, survey results from a sample of design practitioners are presented alone. Findings considered relationships between mediating design tool and object embodiments during an initial analysis of the survey data. A second section of results compares practitioner attitudes towards tool use with results relating to the sample of design students (see Chapter 6, sampling). The section assessed the relationship between both the designer's approach to practice and their use of design tools through exploring the influence design experience had on the survey results. A final section presents findings from both the practitioner and the student sample. The section explores the relationship between the designer and the kinds of embodiments made during design activity; investigating how designer

experience might impact the types of embodiments made across the 10 design tools identified within the taxonomy (Chapter 4).

7.1 Results: Design Tool and Design Embodiment

The following section (7.1) presents the survey findings in terms of practitioner responses to the 10 design tools identified within the taxonomy (Chapter 4):

1. Hand Sketching
2. Digital Sketching
3. Sketch Modelling
4. 3D Printing
5. Digital Graphics Tools
6. Conventional Graphics Tools
7. 3D CAD
8. Model Making
9. Rapid Prototyping
10. 2D CAD

This section explores the data in terms of relationships between the design tool and the kinds of object embodiments afforded through its use. Figure 7.1 shows the area of the Model of Design Activity and Tool Use this analysis of survey findings aimed to explore:

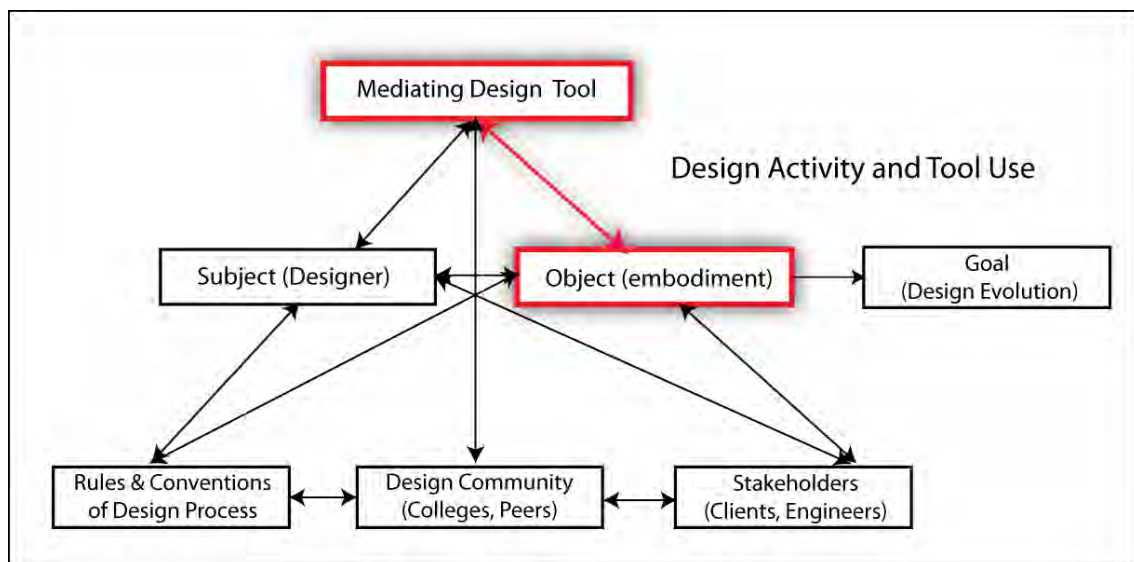


Figure 7.1 Relationship between mediating design tool and design embodiment

Each of the 10 design tools used in the survey is presented in this section. 8 charts are presented for each of the 10 tool, one for each of the 8 Likert-scale questions included in the survey (Chapter 6). The question each of the charts relates to is stated below each chart. The vertical axis presents results as percentages for each of the 5 items included in the Likert-scale question (Chapter 6, Coding and Analysis). The horizontal axis shows the 5 items of the Likert-scale survey questions (Strongly agree, Agree, Neutral, Disagree, Strongly Disagree). All graphs are accompanied by a discussion of results.

7.3.1 Hand Sketching

Hand sketching (design embodiment through paper and pen) was identified as used most often in support of concept design practice and classified within the taxonomy under concept design (Chapter 4). Survey Question 1 related to the ability of hand sketching to support the embodiment of detail (UTC Level of Detail, Figure 7.2):

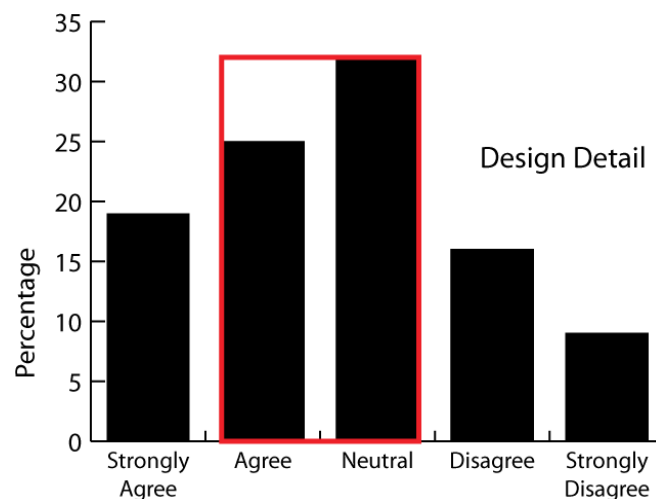


Figure: 7.2 Hand sketching is useful in the representation of design detail
(UTC: Level of Detail)

The results suggested that practitioners were either indifferent in their attitude (32% neutral rating) or tended to agree that sketching supports the embodiment of design detail (strongly agree 18%, agree 25%). This was unexpected as sketching is often discussed as a tool for conceptual, divergent design practice; ambiguity and form rather than design detail. The results also indicated that practitioners consider the tool effective in supporting the embodiment of artistic/creative form however (Figure 7.3):

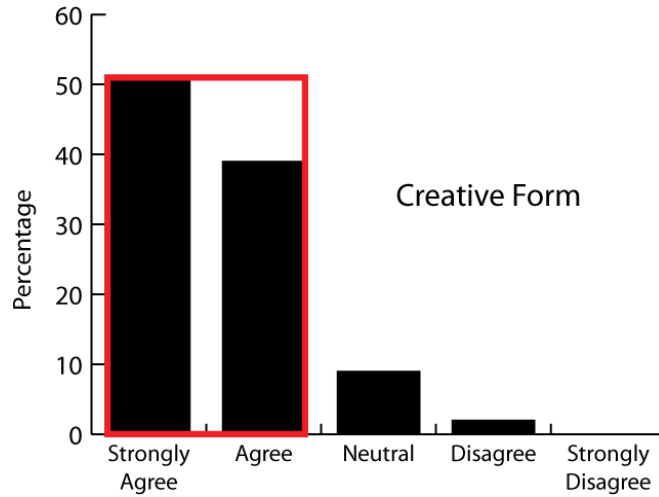


Figure: 7.3 Hand sketching is useful in representing artistic/creative form
(UTC: Level of Detail)

Survey Question 3 asked about sketching’s ability to support the unambiguous representation of design intent (Figure 7.4):

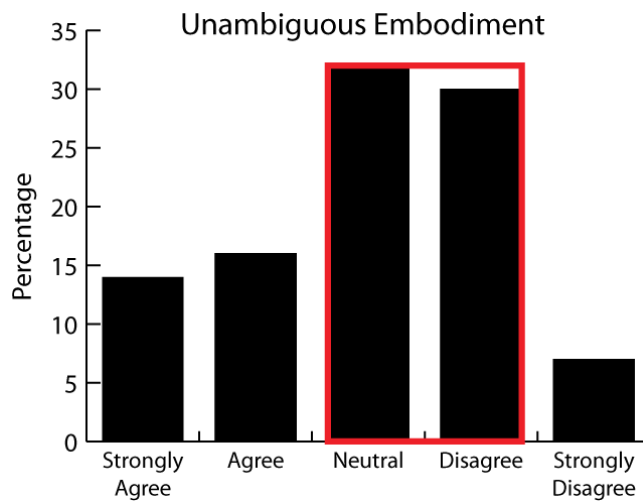


Figure 7.4 Hand sketching is useful in representing ideas unambiguously
(UTC: Level of Ambiguity)

Results showed more negative responses to this question (Neutral 32%, Disagree 30%). However the practitioners agreed (67%) or strongly agreed (27%) sketching is effective in the lateral transformation of ideas (Figure 7.5):

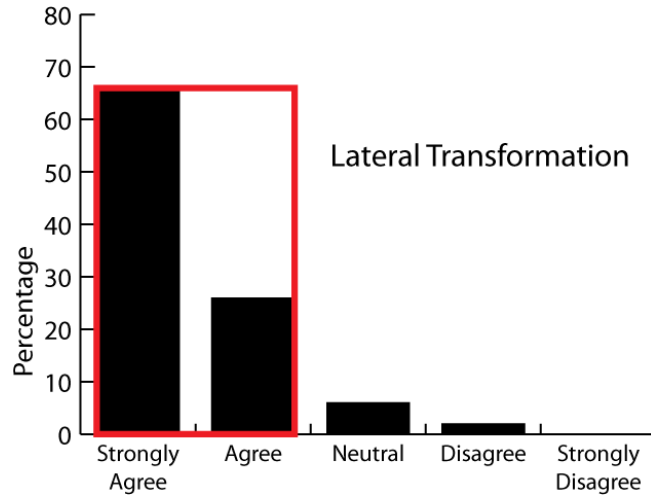


Figure 7.5 Hand sketching is useful for design work that moves easily between ideas (UTC: Transformational Ability)

A majority of practitioners also indicated that they agreed (36%) or strongly agreed (38%) that sketching is effective in supporting vertical transformation during design embodiment (Figure 7.6):

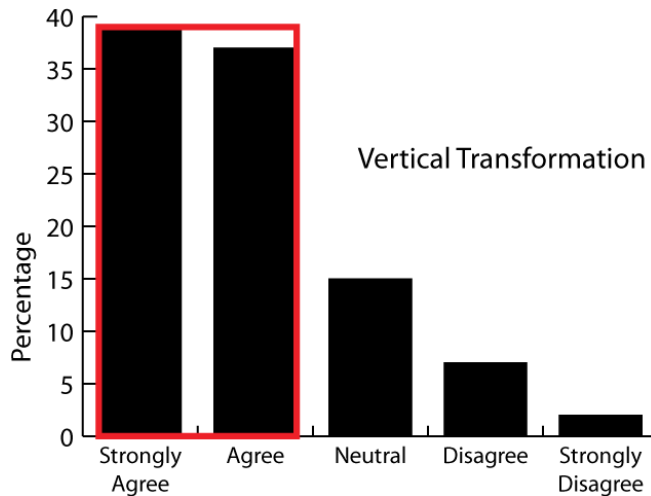


Figure 7.6 Hand sketching is useful for design work on variations of the same design idea (UTC: Transformational Ability)

These results suggested practitioners consider sketching effective in support of both lateral (divergent) and vertical (convergent) design practice.

The practitioner either strongly agreed (28%), agreed (38%) or were indifferent (26%) in response to hand sketching's ability to embody design intent that may communicate high Level of Commitment (Figure 7.7):

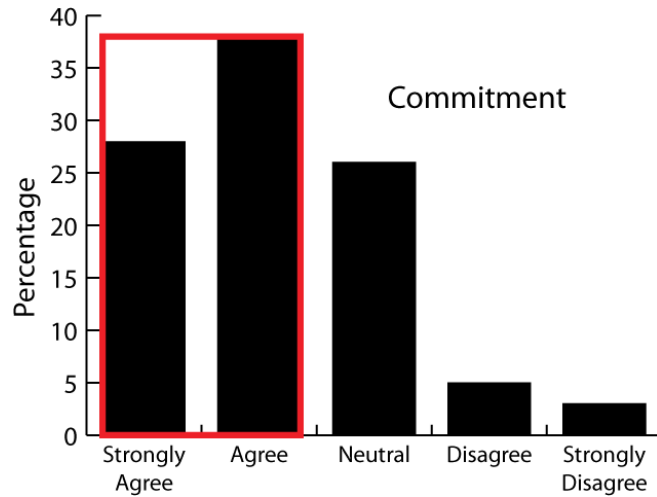


Figure 7.7 Hand sketching tool use communicates high levels of commitment
(UTC: Level of Commitment)

Finally, practitioners' registered positive responses towards sketching's ability to support communication of design intent to others (Figure 7.8) and reflection-in-action (Figure 7.9):

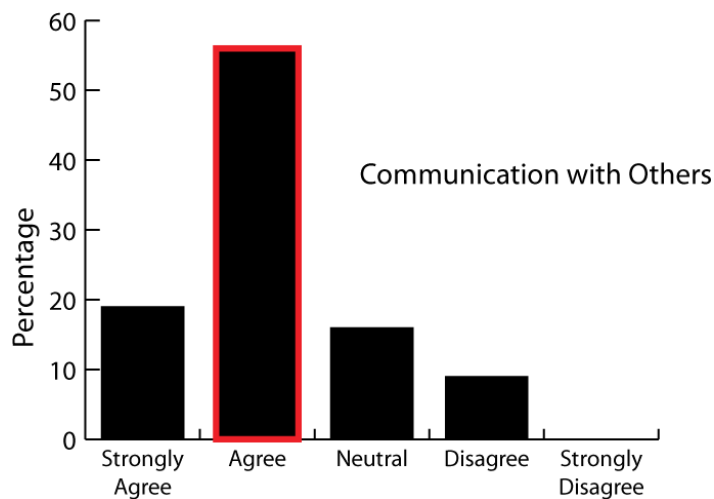


Figure 7.8 Hand sketching is useful for communicating intentions to others
(UTC: Mode of Communication)

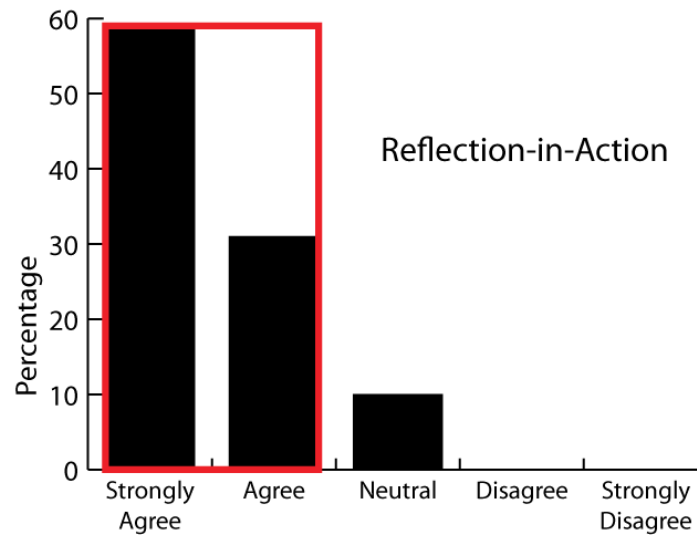


Figure 7.9 Hand sketching aids reflection and the generation of ideas
(Mode of Communication)

In terms of the influence of sketching upon design embodiment (the relationship between the implicit character of design tool and the object embodiments made through its use), the results indicated that practitioners consider sketching effective in supporting a variety of design embodiments. Intuitively, attitudes towards the ability of sketching to support those UTCs associated with divergent conceptual design were positive (e.g. embodiment of creative form; lateral transformations and Reflection-in-Action). However, the findings also indicated that practitioners considered sketching effective in support of the kinds of embodiments seen during a more convergent and detailed stage in studio practice (e.g. embodiment of engineering detail; support of vertical transformations, and commitment to design intentions). It suggests the practitioners regard sketching as a flexible and dynamic tool, able to support a variety of design activities at different stages of practice (see Chapter 8, interview results). This may also indicate the influence of the practitioner in the ways sketching tools may be manipulated to achieve different design activities, and that the dynamic character of the sketching tool make it effective across the design process.

7.3.2 Digital Sketching Tools

Like hand sketching, results towards digital sketching (through graphics tablet and software such as Adobe's Sketchbook Pro) indicated that the practitioners feel the tool is effective in support of the kinds of design embodiment seen both during divergent concept design and more convergent detail design activity. As with hand sketching, practitioners rated digital sketching positively in its ability to support the embodiment of creative form (Figure 7.10, 49% strongly agree, 30% agree):

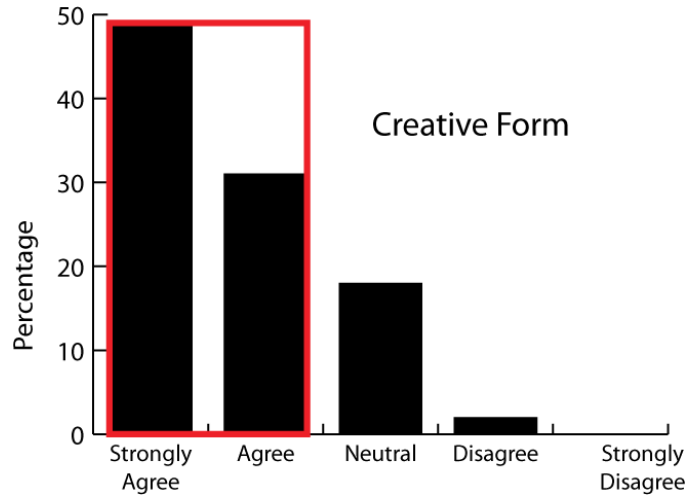


Figure 7.10 Digital sketching is useful for representing artistic/creative form (UTC: Level of Detail)

Practitioners also rated digital sketching highly in its ability to support movement from one idea to another new idea (Figure 7.11: strongly agree 42%, agree 27%):

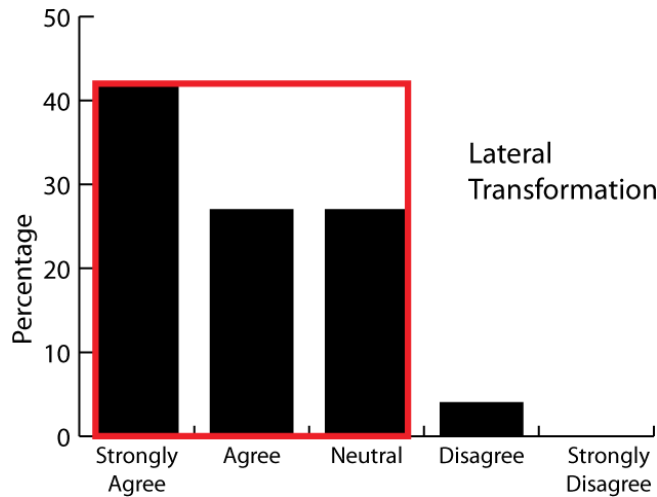


Figure 7.11 Digital sketching is useful for design work that moves easily between ideas (UTC: Transformational Ability)

and digital sketching's ability to support reflection-in-action (Figure 7.12: strongly agree 42%, agree 32%):

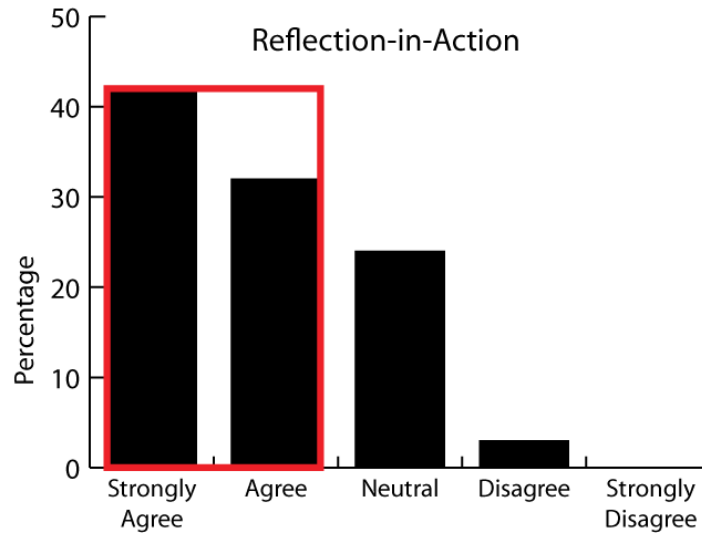


Figure 7.12 Digital sketching aids reflection and the generation of idea
(UTC: Mode of Communication)

Relating to detail design, the results suggested that practitioners considered digital sketching, like hand sketching, effective in the embodiment of design detail (Figure 7.13: strongly agree 20%, agree 27%), but that a similar number of responses were registered as neutral or negative (Figure 7.13: neutral 38%, disagree 20%):

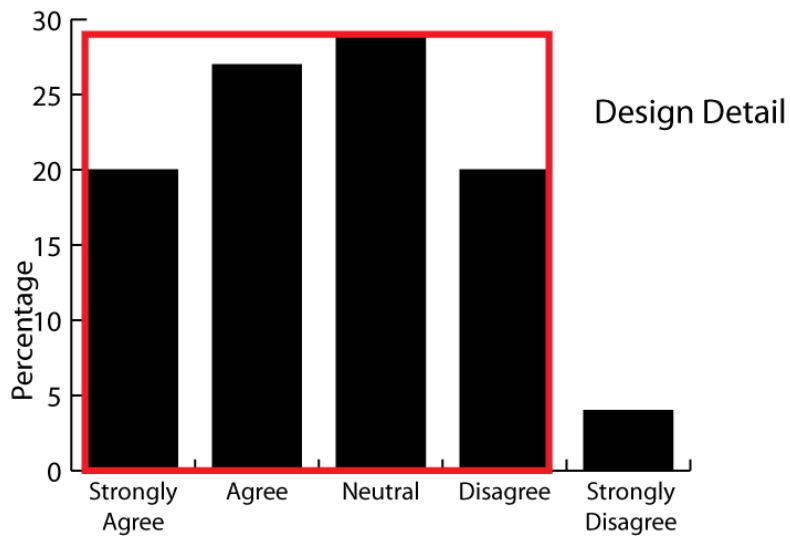


Figure 7.13 Digital sketching is useful in representing design detail
(UTC: Level of Detail)

The ability of sketching to support vertical transformations (Figure 7.14) and the embodiment of design intent that appears to be more committed (Figure 7.15) also received positive responses:

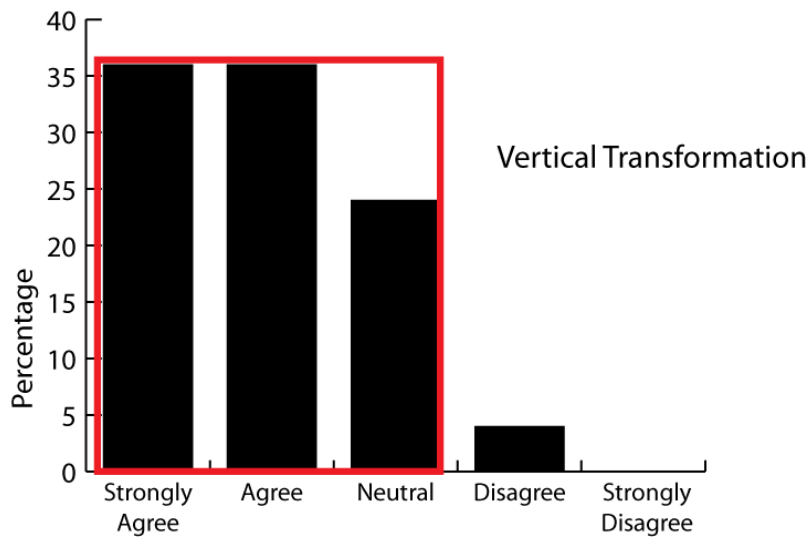


Figure 7.14 Digital sketching is useful for design work on variations of the same design idea (UTC: Transformational Ability)

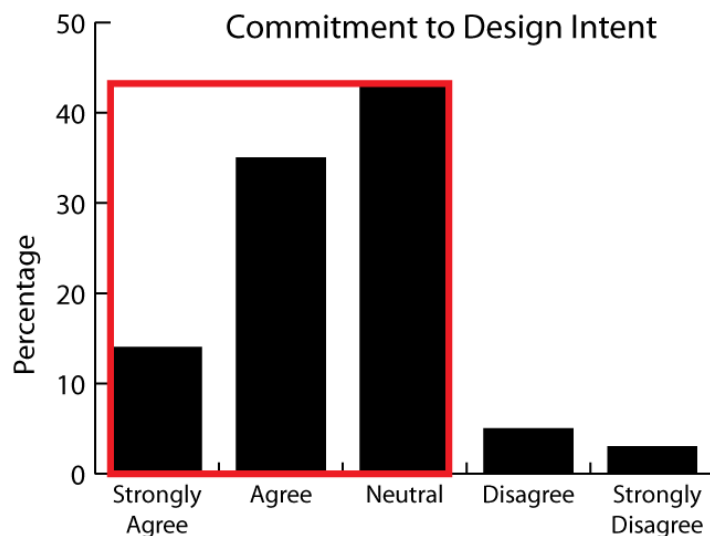


Figure 7.15 Digital sketching communicates a high Level of Commitment (UTC: Level of Commitment)

As with hand sketching, results indicated similarities in the character of hand and digital sketching tools in supporting design embodiments of various kinds and the practitioner’s exploitation of this in their use of the tool for different purposes during design activity. The tool’s character appears to influence the ways in which it is used, in

so far as the dynamic character of sketching (hand and digital) allow its use in a variety of different design embodiments.

7.3.3 Sketch Modelling Tools

As with sketching tools practitioners rated sketch modelling (model making using foam, card and quickly malleable materials) positively in terms of those characteristics associated with divergent concept design. 40% of practitioners agreed and 29% strongly agreed that sketch modelling was effective in the embodiment of artistic/creative form (Figure 7.16):

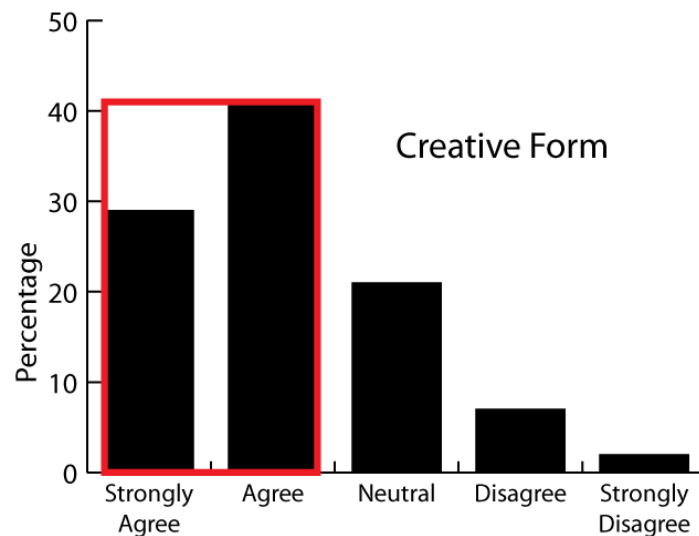


Figure 7.16 Sketch modelling is useful for representing artistic/creative form
(UTC: Level of Detail)

Practitioners also rated sketch modeling effective in supporting the lateral transformation of design ideas (Figure 7.17: strongly agree 45%, agree 40%) and supportive of reflection-in-action (Figure 7.18: strongly agree 51%, agree 35%).

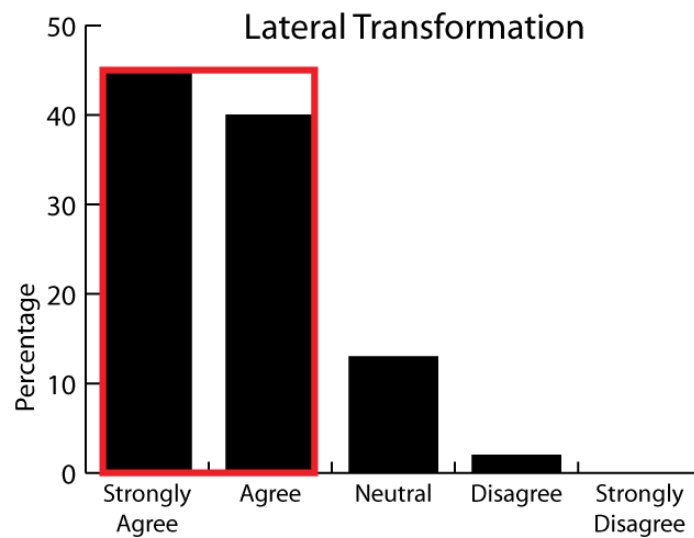


Figure 7.17 Sketch modelling is useful for design work that moves easily between ideas
(UTC: Transformational Ability)

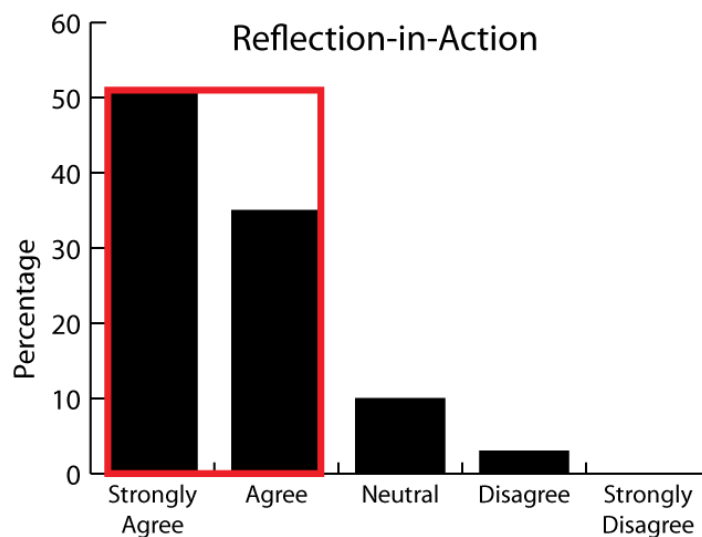


Figure 7.18 Sketch modelling aids reflection and the generation of ideas
(UTC: Mode of Communication)

However, like hand and digital sketching tools, practitioner attitudes towards sketch modelling's ability to support detailed design embodiment (Figure 7.19), vertical transformation of design ideas (Figure 7.20) and commitment to design intent (Figure 7.21) also tended to be more positive:

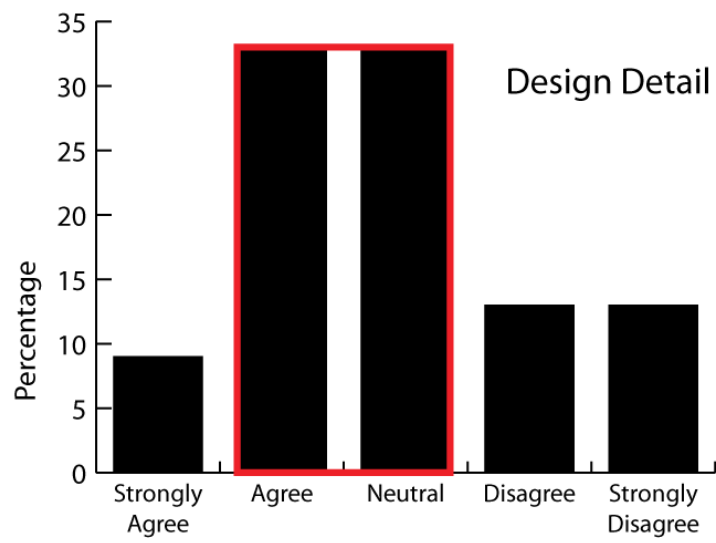


Figure 7.19 Sketch modeling is useful in representing design detail
(UTC: Level of Detail)

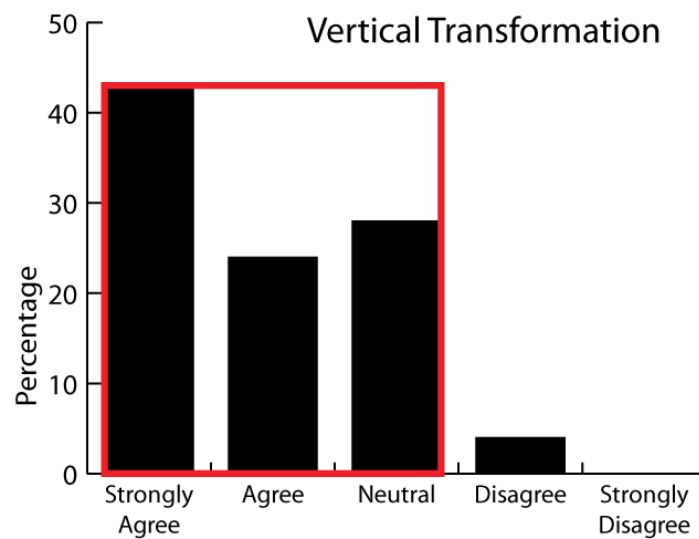


Figure 7.20 Sketch modeling is useful for design work on variations of the same design idea
(UTC: Transformational Ability)

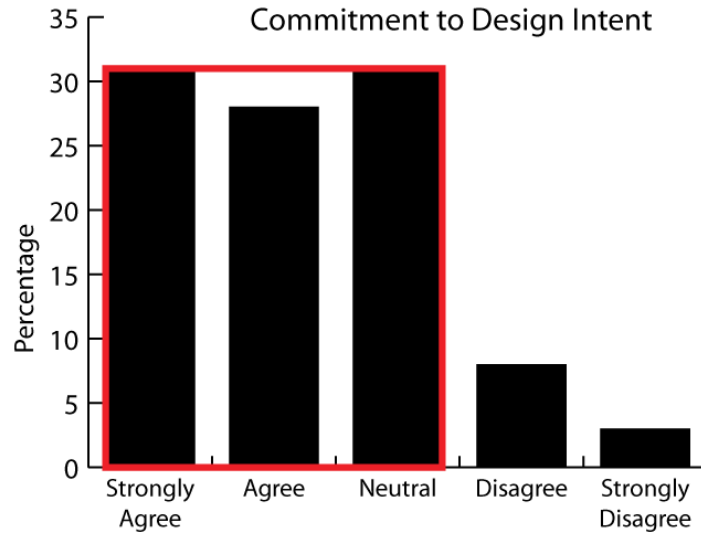


Figure 7.21 Sketch modelling communicates commitment to design intent
(UTC: Level of Commitment)

The practitioners gave mixed responses towards the tool's ability to support unambiguous embodiment, a characteristic often associated with detailed design practice (Figure 7.22: agree 27%, neutral 41%, disagree 19%, Figure 7.22). This suggested individuals within the sample group may take different approaches to the use of sketch modelling tools:

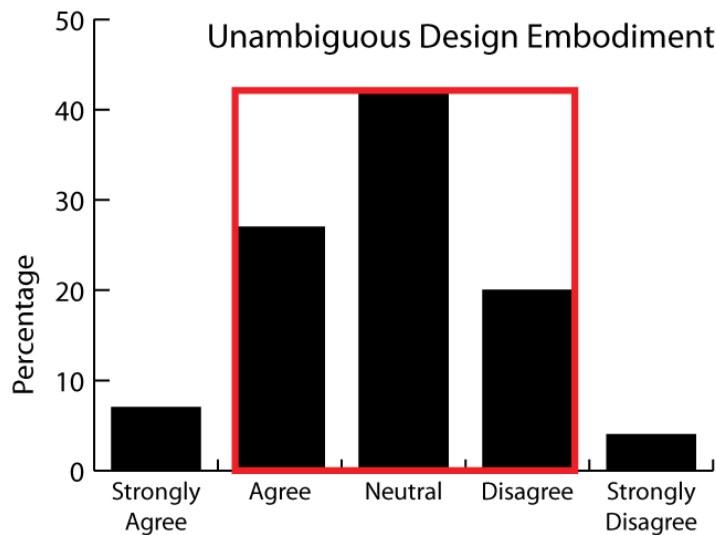


Figure 7.22 Sketch modeling is useful for representing ideas unambiguously
(UTC: Level of Ambiguity)

The results indicated the ability of sketch modelling to support design embodiment during divergent conceptual design practice (seen through responses to those UTCs

associated with concept design, embodiment of creative form, reflection-in-action, lateral transformations). However, like hand and digital sketching, practitioners indicated some positive attitudes towards the tool's ability to support the kinds of design embodiment often associated with development and detail design activity: vertical transformations, unambiguity and detailed embodiment of design intent. Survey findings suggested that practitioner attitudes towards the tool might not map intuitively onto the tool's use in practice: that is to say that tools often associated with divergent conceptual design activity also received positive responses to UTCs associated with convergent design. It is unclear from the survey findings alone how this may influence tool use in practice. However, it seems reasonable to infer that, although there is a relationship between the implicit character of design tools and their use during practice, this relationship is also dependent upon the kinds of use the practitioner makes of the tool; the tool-user's influence on tool use.

7.3.4 3D Printing Tools

As with sketching tools, practitioners rated 3D printing (physical design embodiment through manipulation of 3D CAD which is then printed in 3D) highly in its ability to support the types of design embodiments associated with divergent, concept design. However results were also more mixed across the items of the Likert-scales compared to sketch modelling. A greater percentage of practitioners registered a neutral or disagree response for those characteristics associated with concept design practice (support of lateral transformations, Figure 7.23 and reflection-in-action, Figure 7.24:

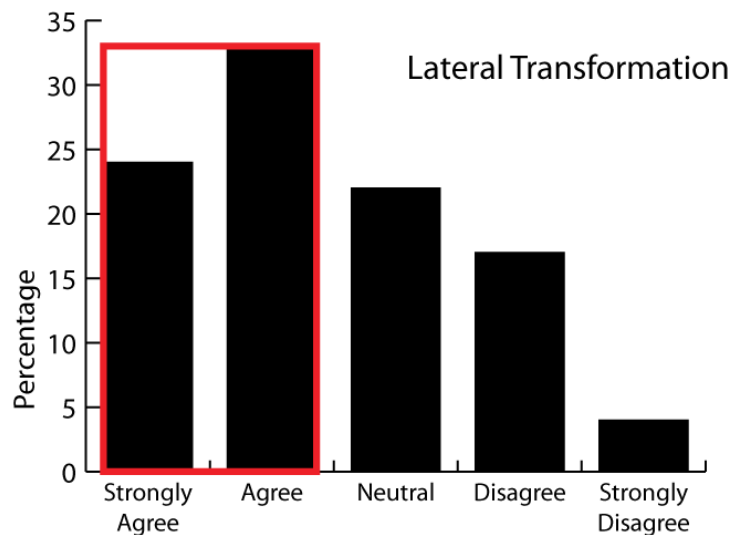


Figure 7.23 3D Printing is useful for design work that moves easily between ideas
(UTC: Transformational Ability)

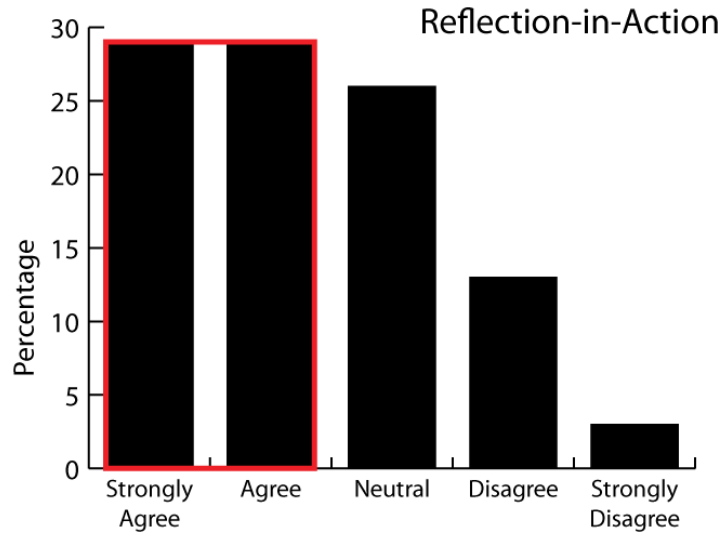


Figure 7.24 3D Printing aids reflection and the generation of ideas
(UTC: Mode of Communication)

Practitioners also rated 3D printing positively in its ability to support those characteristics associated with development and detail design: the vertical transformation of design ideas Figure 7.25, embodiment of detail Figure 7.26, unambiguous embodiment, Figure 7.27 and commitment to design intent, Figure 7.28:

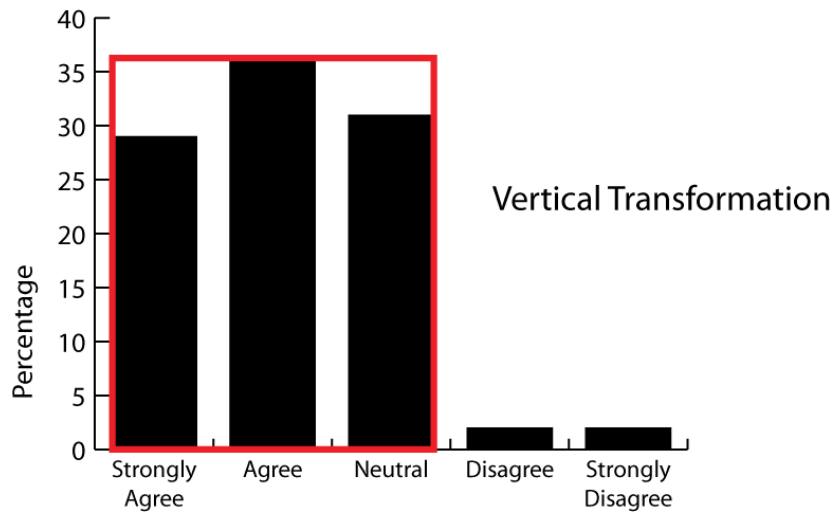


Figure 7.25 3D Printing is useful for design work on variations of the same design idea
(UTC: Transformational Ability)

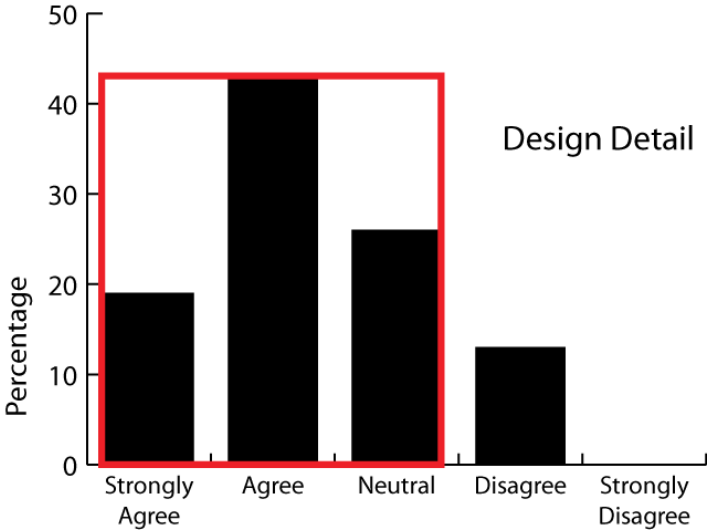


Figure 7.26 3D Printing is useful in representing design detail (UTC: Level of Detail)

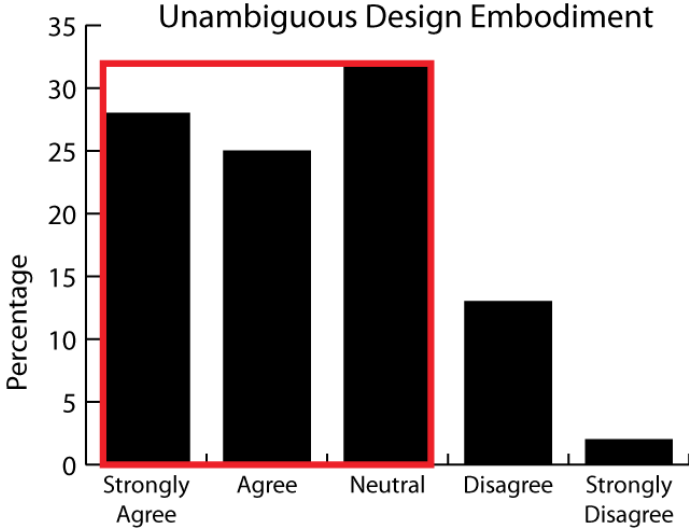


Figure 7.27 3D Printing is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

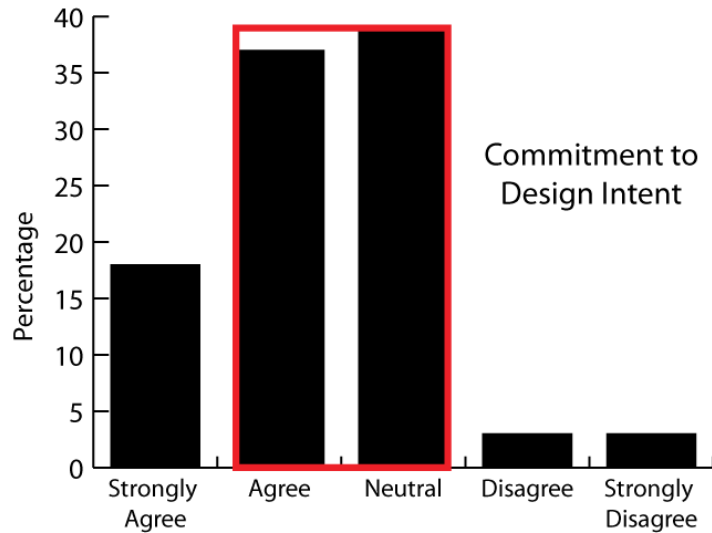


Figure 7.28 3D Printing communicates high levels of commitment (UTC: Level of Commitment)

These results indicated practitioners also considered 3D printing more effective in support of UTCs often associated with detail design. Findings also indicated that the sample agreed (47%) or strongly agree (38%) that 3D printing was effective in communication of design intent to others (Figure 7.29):

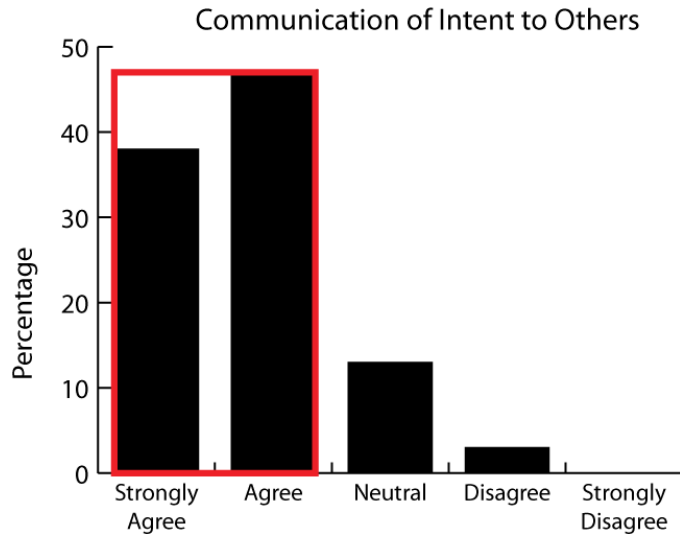


Figure 7.29 3D Printing is useful for communicating intentions to others (UTC: Mode of Communication)

3D printing tended to be rated more positively in its ability to support the kinds of embodiments associated with concept design: reflection-in-action, lateral transformations. This suggests a relationship between the design tool and its use in

practice. However, survey results also suggested that practitioners hold positive attitudes towards the ability of concept design tools to support the types of embodiments associated with convergent design activity, the embodiment of design detail, vertical transformations, unambiguously, and commitment to design intent.

The findings indicated the use of concept design tools in support of the kinds of design embodiment associated with a convergent, detailed design practice: representation of detail, vertical transformations and commitment to design intent. Although the findings suggest a relationship between the affording characteristics of concept design tools in their ability to support concept design activity, practitioner attitudes indicated their use in embodiment at different stages in studio practice; tools often associated with concept design are used to support a more convergent design activity. This indicated both the influence of context of use and the designer's own influence.

7.3.5 Digital Graphics Tools

Digital graphics tools (Adobe Photoshop, Illustrator) were classified within the taxonomy under development design (Chapter 4). The survey results relating to these tools were particularly mixed. Practitioners agreed or strongly agree that digital graphics tools supported the embodiment of form (Figure 7.30).

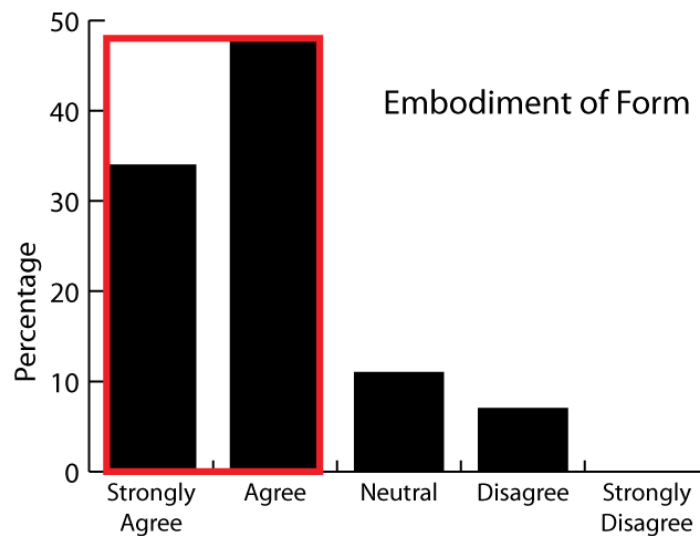


Figure 7.30 Digital graphics tools are useful for representing artistic/creative form
(UTC: Level of Detail)

However, 20% of the respondents strongly agree and 27% agreed that digital graphics tools are also effective in support of detailed design embodiment (Figure 7.31):

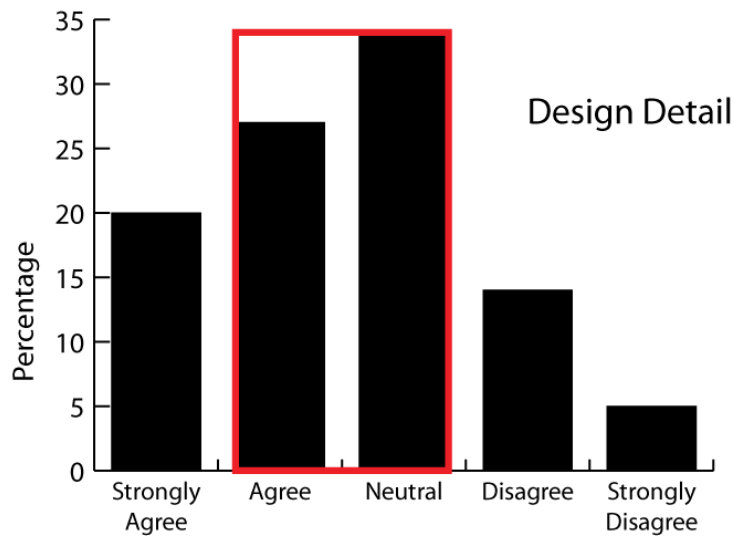


Figure 7.31 Digital graphics tools are useful for representing design detail
(UTC: Level of detail)

In terms of the tool's ability to support either lateral (Figure 7.32) or vertical transformations (Figure 7.33), in both cases practitioners tended to register agreement or strong agreement:

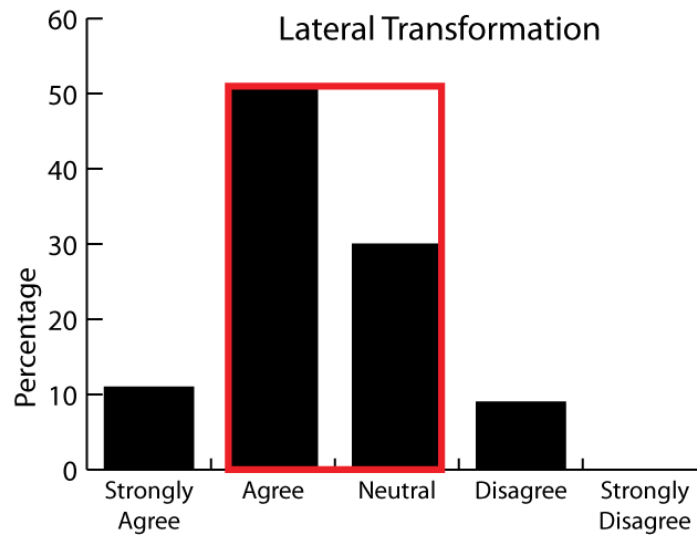


Figure 7.32 Digital graphics tools are useful for design work that moves easily between ideas
(UTC: Transformation Ability)

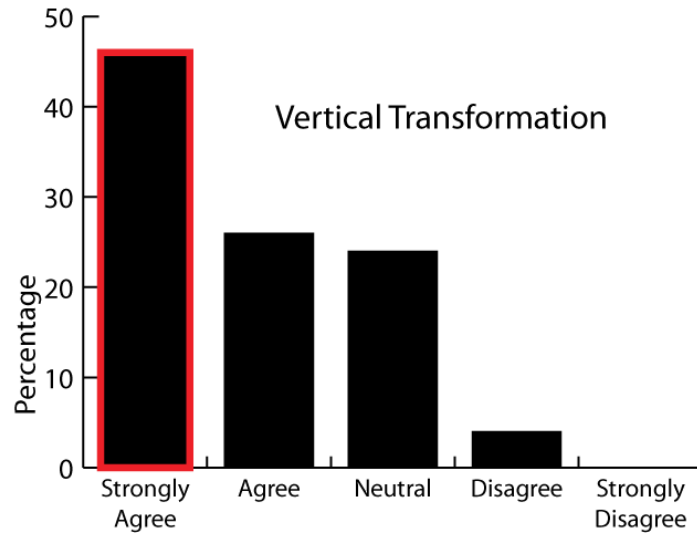


Figure 7.33 Digital graphics tools are useful for design work on variations of the same design idea (UTC: Transformational Ability)

Practitioners also indicated agreement or were neutral in their response towards the ability of digital graphics tools to support the unambiguous embodiment of design intent (Figure 7.34: agree 47%, neutral 30%):

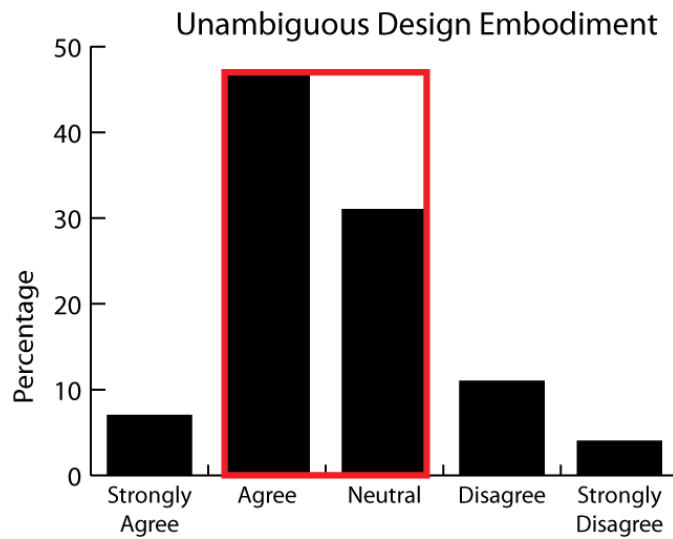


Figure 7.34 Digital graphics tools are useful for representing ideas unambiguously (UTC: Level of Ambiguity)

The results indicated that practitioners held similar attitudes towards the tool's use in the embodiment of intentions that communicate commitment to design ideas (Figure 7.35: agree 45%, neutral 37%):

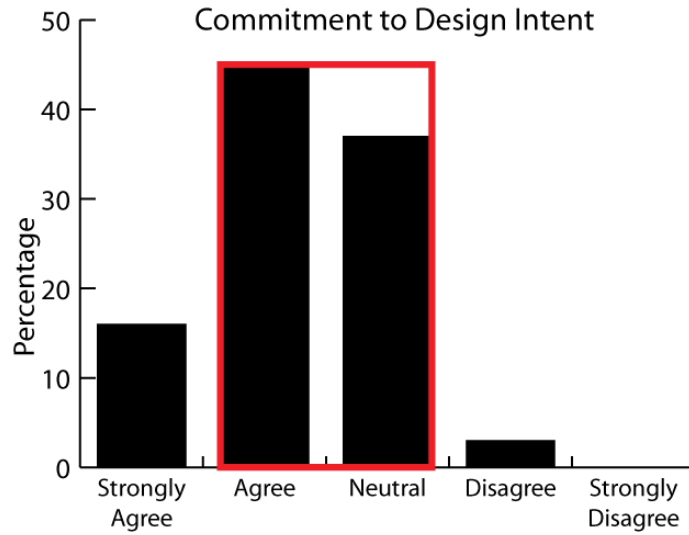


Figure 7.35 Digital graphics tools communicate a high level of commitment (UTC: Level of Commitment)

Finally, the results indicated that practitioners felt that digital graphics tools are effective in the communication of design intent to others (Figure 7.36: agree 52%, strongly agree 21%) and in support of reflection-in-action (Figure 7.37: agree 45%, strongly agree 15%):

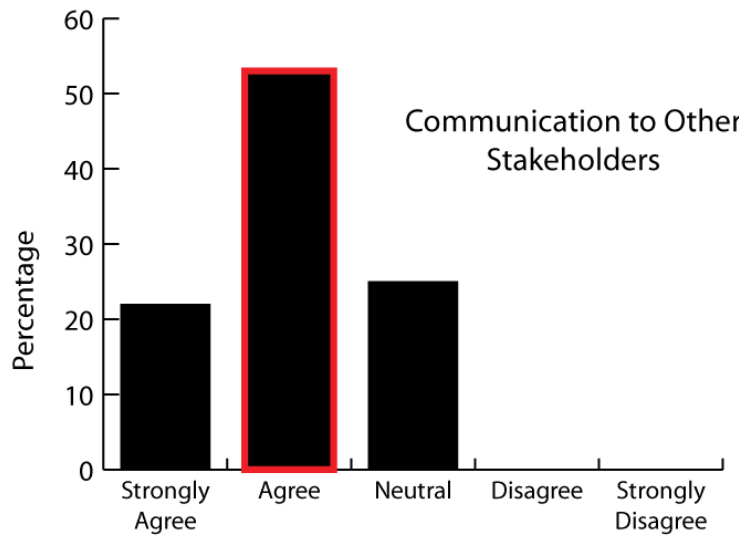


Figure 7.36 Digital graphics tools are useful for communicating intentions to others (UTC: Mode of Communication)

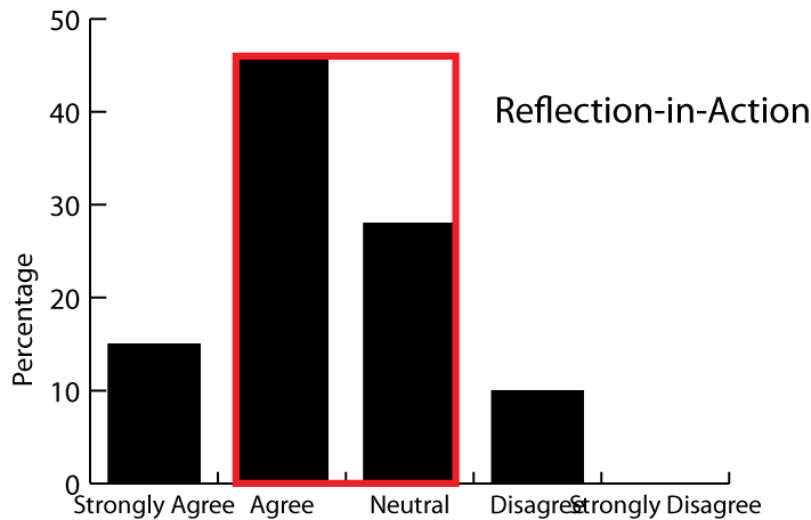


Figure 7.37 Digital graphics tools aid reflection and the generation of ideas
(UTC: Mode of Communication)

Mixed responses across the sample to the attitude questions may indicate that the types of embodiments made through the use of digital graphics tools are dependent on the designer's idiosyncratic use of the tool. Although the character of the tool has implications for the kinds of embodiments made, the relationship between tool use and design embodiment is also critically informed by the tool's use by the designer, and the context of use: the various requirements of practice, the design practitioner's own skills, experiences and working habits.

7.3.6 Conventional Graphics Tools

As with digital graphics tools, practitioner attitudes towards the ability of the conventional graphics tool (marker rendering for example) to support the embodiment of creative form tended towards agreement and strong agreement, but to a greater degree than digital graphics tools (Figure 7.38: agree 49%, strongly agree 27%):

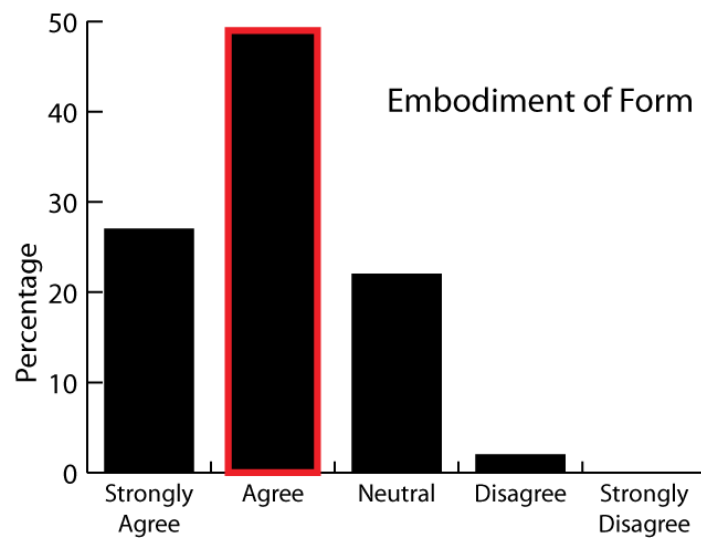


Figure 7.38 Conventional graphics tools are useful for representing artistic/creative form (UTC: Level of Detail)

Practitioner attitudes towards the tool's ability to support detailed embodiment were mixed across the sample group (Figure 7.39):

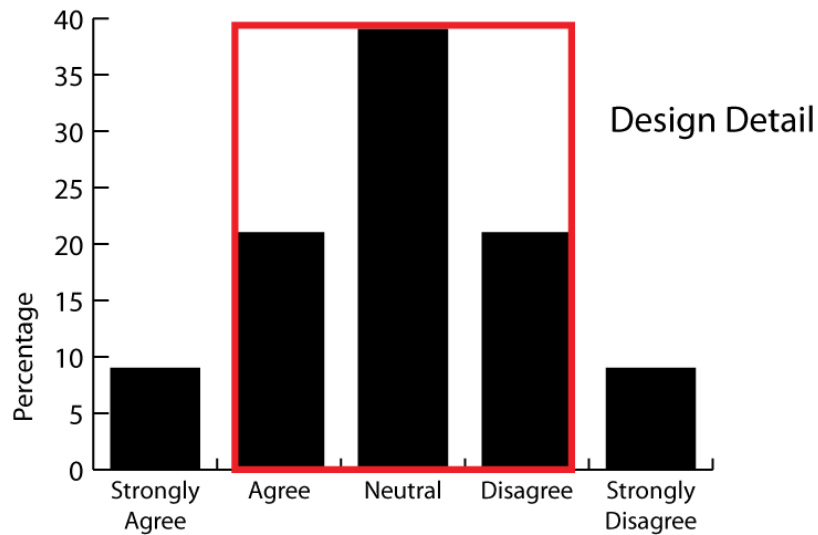


Figure 7.39 Conventional graphics tools are useful in representing design detail (UTC: Level of Detail)

As with digital graphics tools, the results indicated the practitioners were more likely to agree than disagree with the suggestion that the use of conventional graphics tools

resulted in the unambiguous embodiment of design intentions (Figure 7.40), although some 39% indicated a neutral response:

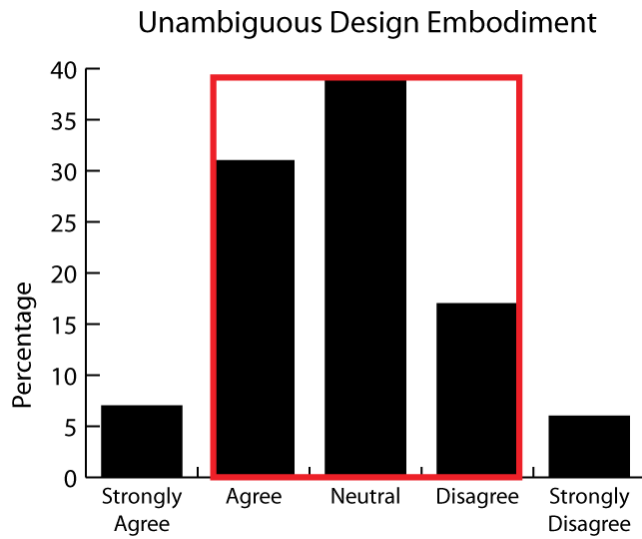


Figure 7.40 Conventional graphics tools are useful for representing ideas unambiguously (UTC: Level of Ambiguity)

The results also suggested that practitioners consider conventional graphics tools as being effective in the lateral (Figure 7.41) and vertical (Figure 7.42) transformation of design ideas, although in each case, approximately one third registered a neutral response:

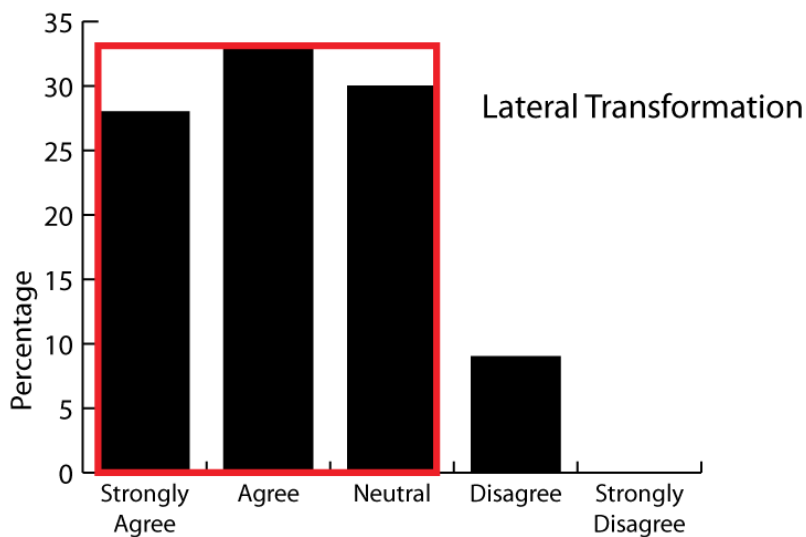


Figure 7.41 Conventional graphics tools are useful for design work that moves easily between ideas (UTC: Transformational Ability)

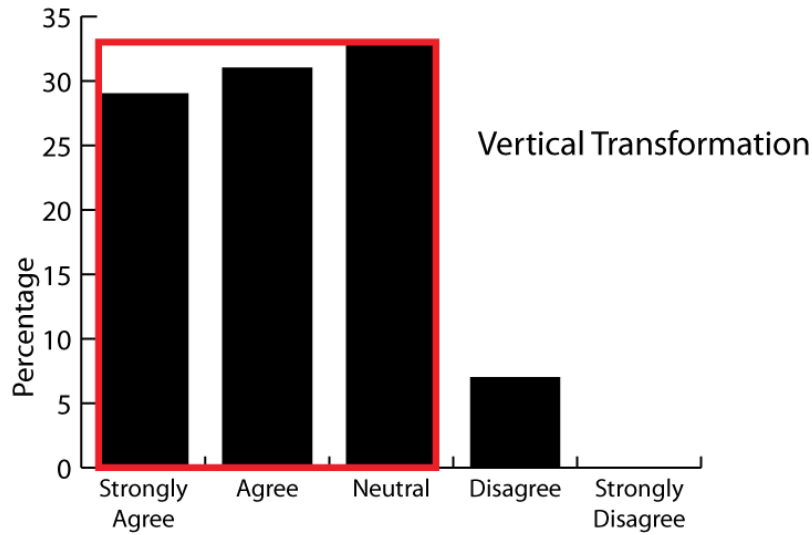


Figure 7.42 Conventional graphics tools are useful for design work on variations of the same design ideas (UTC: Transformational Ability)

Results relating to practitioner attitudes towards the ability of conventional graphics tools to support committed design embodiment (Figure 7.43), communication with others (Figure 7.44) and reflection-in-action (Figure 7.45) were similar to those recorded for digital graphics tools, with practitioners tending to register positive responses):

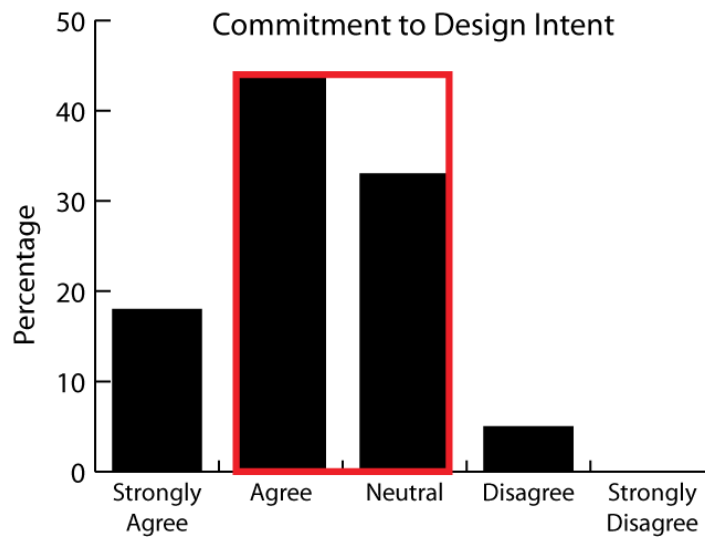


Figure 7.43 Conventional graphics tools communicate a high level of commitment (UTC: Level of Commitment)

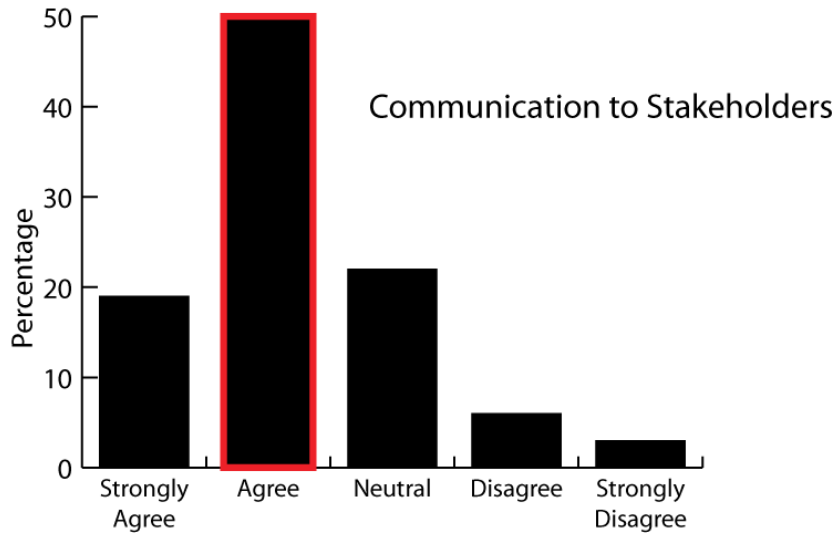


Figure 7.44 Conventional graphics tools are useful for communicating intentions to others (UTC: Mode of Communication)

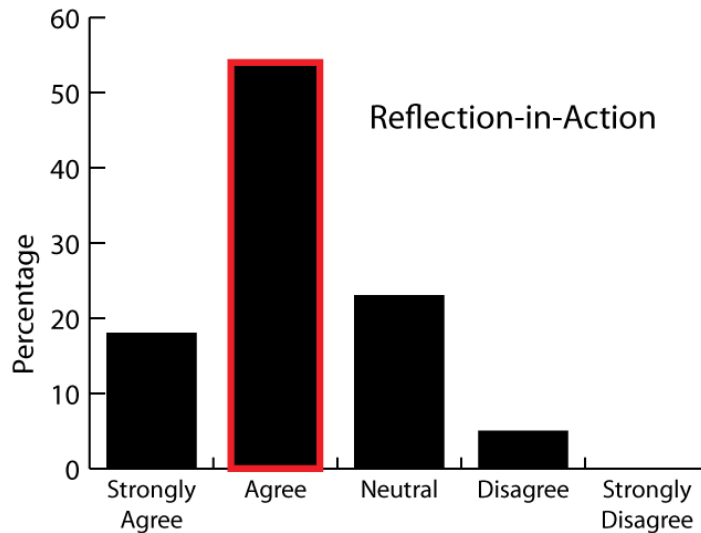


Figure 7.45 Conventional graphics tools aid reflection and the generation of ideas (UTC: Mode of Communication)

These findings may again indicate the influence of the tool’s implicit characteristics: the tool was generally rated more positively in terms of characteristics of embodiment associated with concept design, but that the practitioner has an influence on the ways in which the tool is used in practice, indicated through mixed responses to individual questions across the sample.

7.3.7 3D CAD Tools

3D CAD tools (Solidworks, Rhino, Pro-e) were classified within the taxonomy as tools most often used to support development design. Practitioners rated 3D CAD positively

in its ability to support the embodiment of creative form (Figure 7.46) and design detail (Figure 7.47), although the sample registered more positive responses to 3D CAD's ability to support embodiment of detail than creative form:

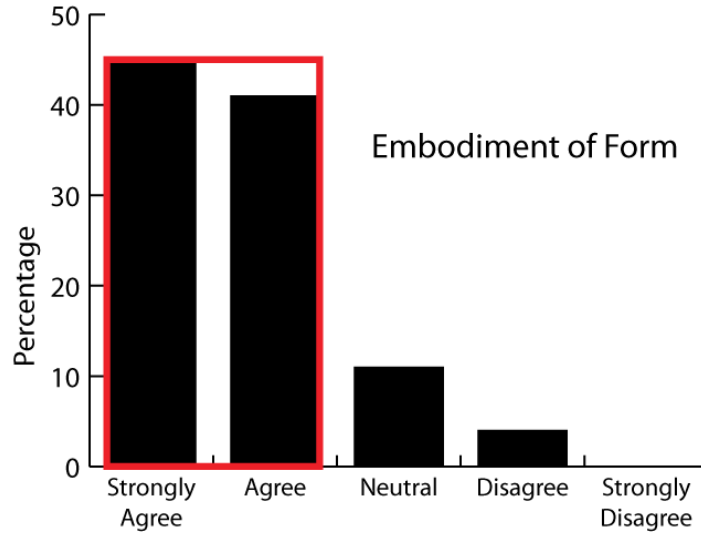


Figure 7.46 3D CAD is useful for representing artistic & creative form (UTC: Level of Detail)

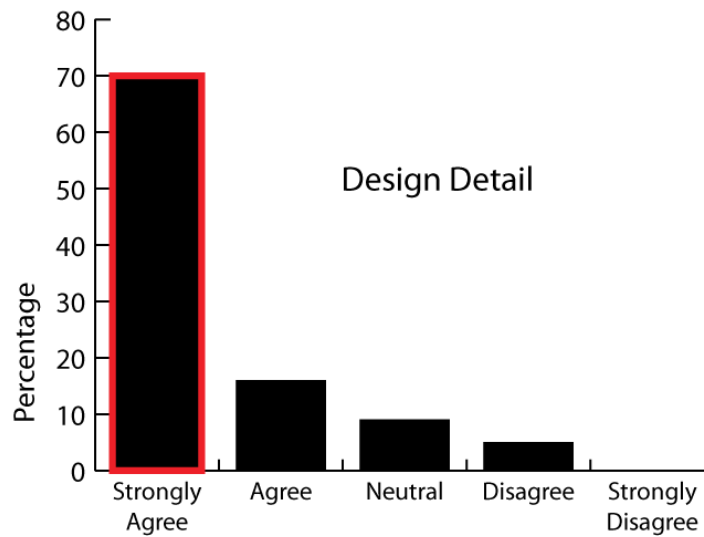


Figure 7.47 3D CAD is useful for representing design detail (UTC: Level of Detail)

This may suggest 3D CAD is used in both the embodiment of less detailed design intention and for more specific embodiment (see also Chapter 8, interview results). Practitioners also agreed (39%) or agreed strongly (51%) that 3D CAD was useful in representing design ideas unambiguously (Figure 7.48):

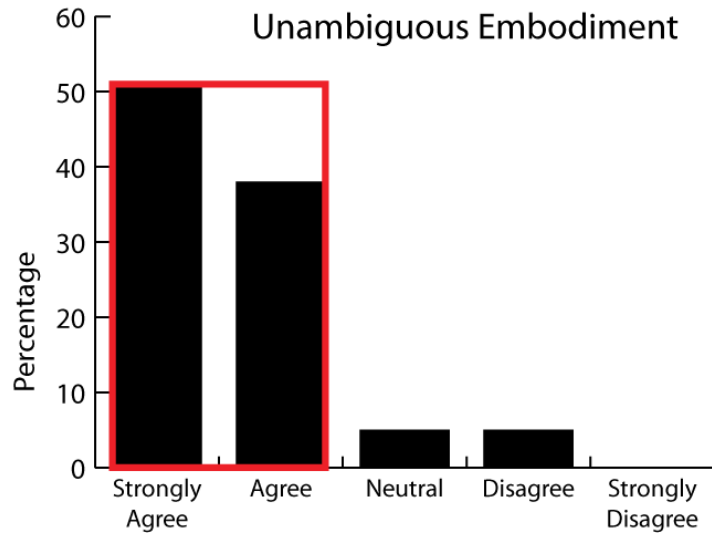


Figure 7.48 3D CAD is useful for representing ideas unambiguously
(UTC: Level of Ambiguity)

In terms of lateral (Figure 7.49) and vertical (Figure 7.50) transformations, practitioners showed a tendency to consider 3D CAD as effective in supporting vertical transformations (strongly agree 60%, agree 38%):

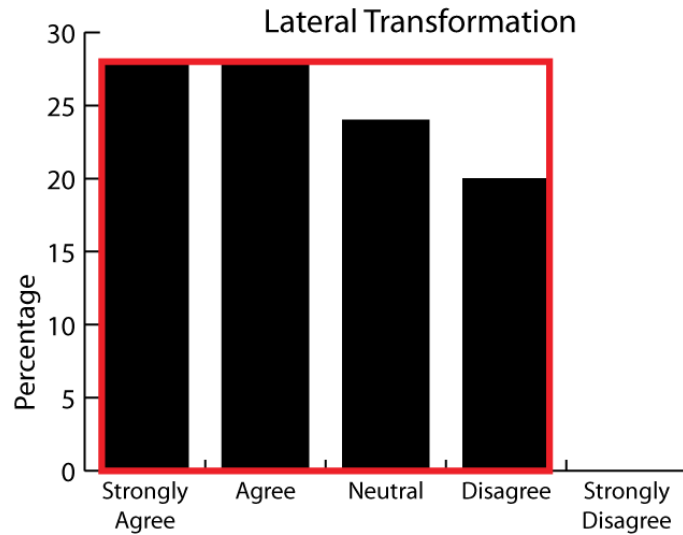


Figure 7.49 3D CAD is useful for design work that moves easily between ideas
(UTC: Transformational Ability)

Results relating to lateral transformation suggested more difference in attitudes across the sample group (Figure 7.49). 28% of practitioners strongly agreed and the same percentage agreed that 3D CAD had the ability to support lateral transformations

during design embodiment (Figure 7.49). However, a further 20% disagreed and 24% were unsure of the tool's ability.

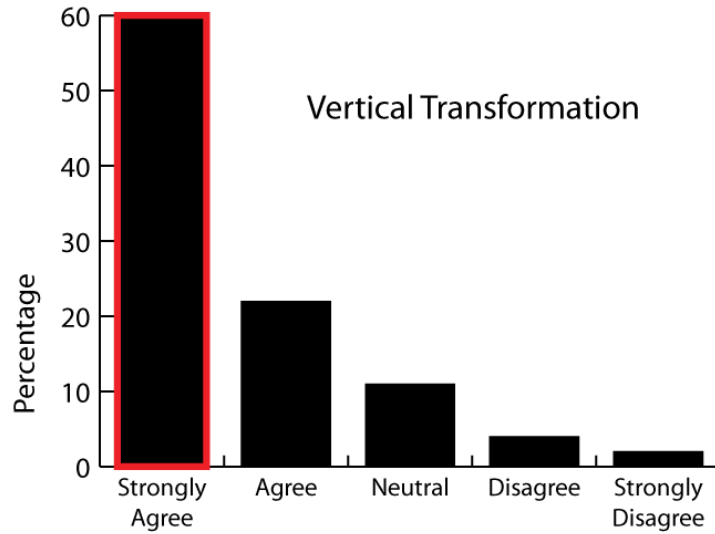


Figure 7.50 3D CAD is useful for design work on variations of the same design idea (UTC: Transformational Ability)

In terms of the design tool's use in communicating both commitment to design intent (Figure 7.51) and the communication of intentions to others (Figure 7.52), practitioners rated 3D CAD positively:

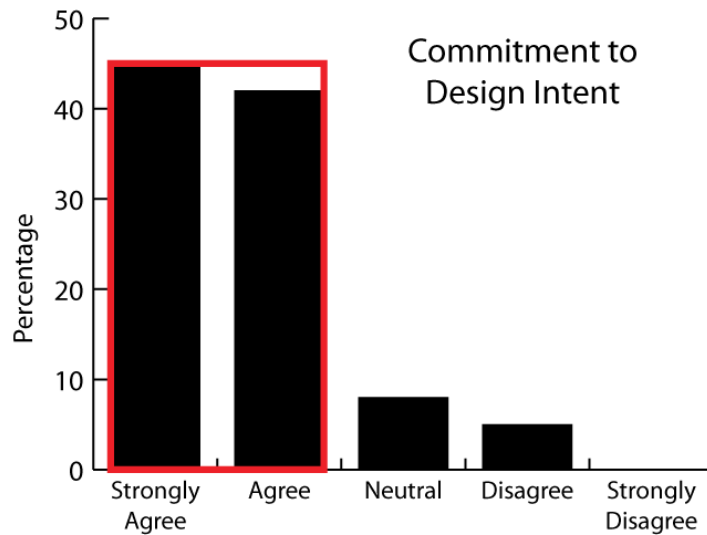


Figure 7.51 3D CAD communicates a high level of commitment (UTC: Level of Commitment)

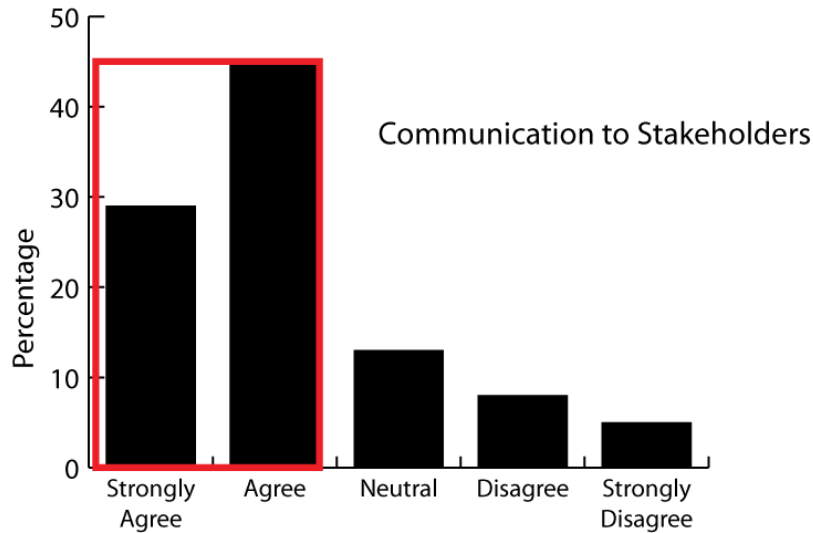


Figure 7.52 3D CAD is useful for communicating intentions to others
(UTC: Mode of Communication)

Finally, with regards the tool's ability to support reflection-in-action, findings suggest a tendency for practitioners to agreed (45%) or strongly agree (29%, Figure 7.53):

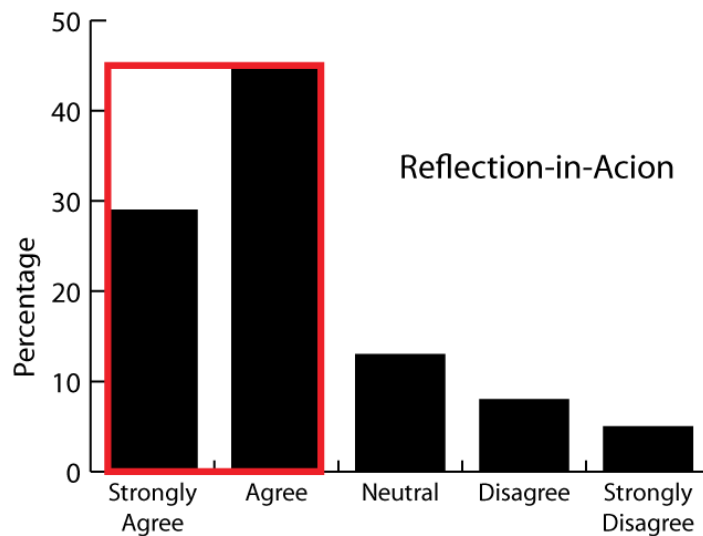


Figure 7.53 3D CAD aids reflection and the generation of ideas
(UTC: Mode of Communication)

Practitioners consistently rated 3D CAD positively across all 8 attitude questions. Some of the dichotomies within the questions showed noticeably stronger weighting of agreement in one direction: more effective in support of design detail compared to creative form; more useful in support of vertical transformation than lateral; and more effective in communication with others than in support of reflection-in-action. These

results, like those relating to hand sketching, indicated that practitioners hold positive attitudes towards the abilities of 3D CAD to embody design intent in a variety of ways.

The responses point to the ways in which practitioners employ 3D CAD to manipulate the character of design embodiment. However the weighting of positivity may also suggest the influence of the tool's own character. 3D CAD is a dynamic tool, but this dynamism is bounded by the implicit nature of the tool-in-hand. Evidence of this is seen in responses suggesting its effectiveness in support of embodiment of detail and vertical transformations, less so for creative form or reflection-in-action. 3D CAD may be used explorative, divergent design but is seen as more effective for a convergent and unambiguous design activity.

7.3.8 Model Making

Like 3D CAD, model making (the use of workshop processes to physically model design intent) registered positive responses, although the results suggested that attitudes were more mixed across the sample group. In terms of the tool's ability to support the embodiment of creative form (Figure 7.54), a majority of practitioners indicated agreement (52%) or strong agreement (30%):

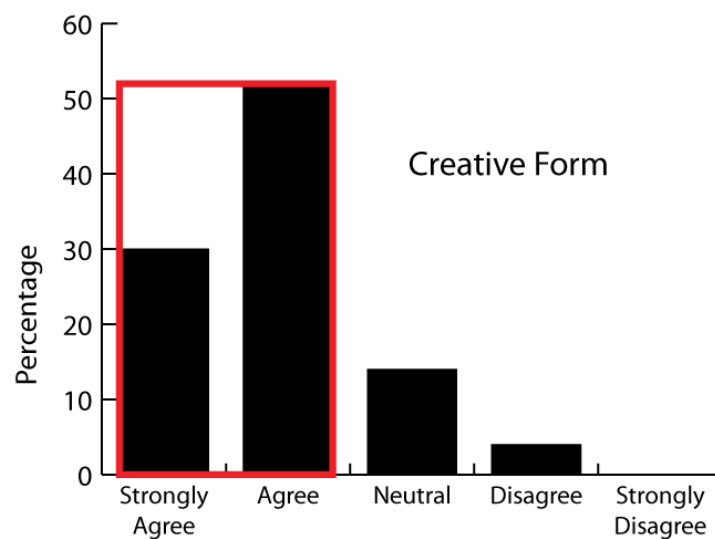


Figure 7.54 Model Making is useful for representing artistic/creative form
(UTC: Level of Detail)

When asked about the tool's ability to support detailed design embodiment (Figure 7.55), responses were more mixed, with 23% of the sample strongly agreeing and a further 30% in agreement. However, the practitioners also registered 13% in disagreement and 32% were neutral:

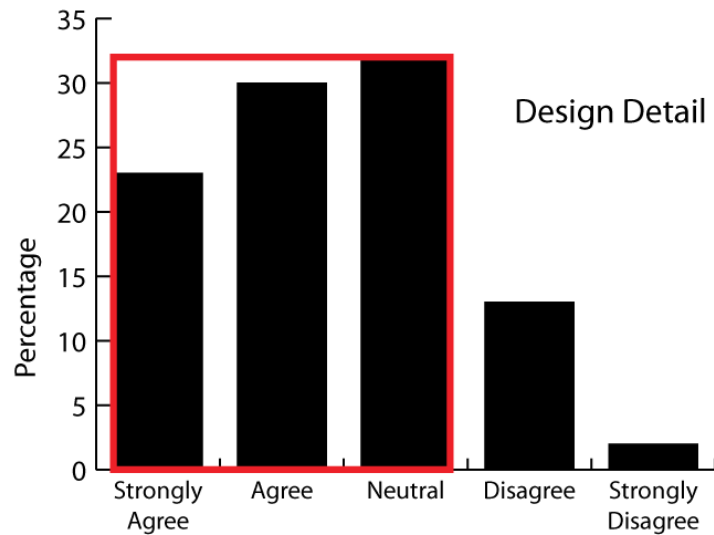


Figure 7.55 Model Making is useful for representing design detail
(UTC: Level of Detail)

This mixed response was also seen in attitudes towards unambiguous embodiment, albeit to a lesser extent with more practitioners in agreement (Figure 7.56):

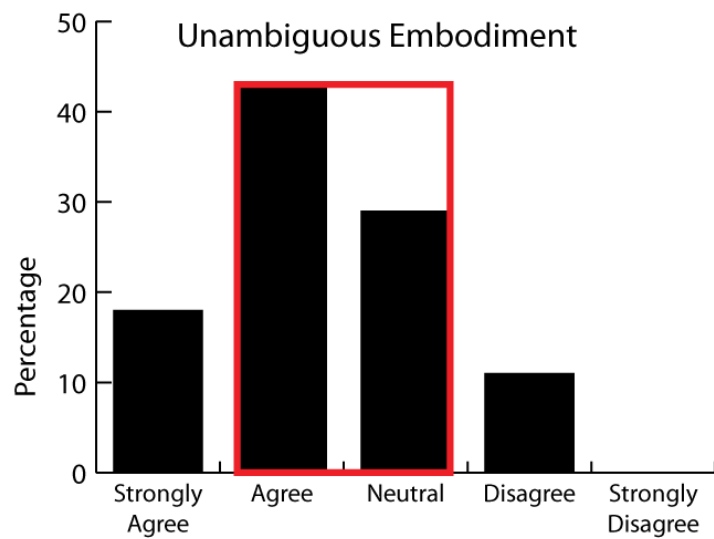


Figure 7.56 Model Making is useful for representing ideas unambiguously
(UTC: Level of Ambiguity)

The responses towards the tool’s ability to support lateral (Figure 7.57) and vertical (Figure 7.58) transformations tended to be positive, although in both cases the percentage of neutral responses was high (lateral transformations 33%, vertical transformations 38%):

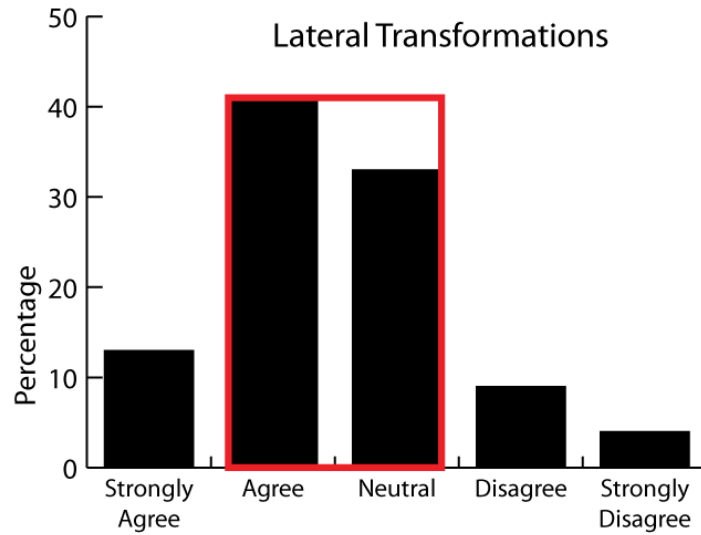


Figure 7.57 Model Making is useful for design work that moves easily between ideas (UTC: Transformational Ability)

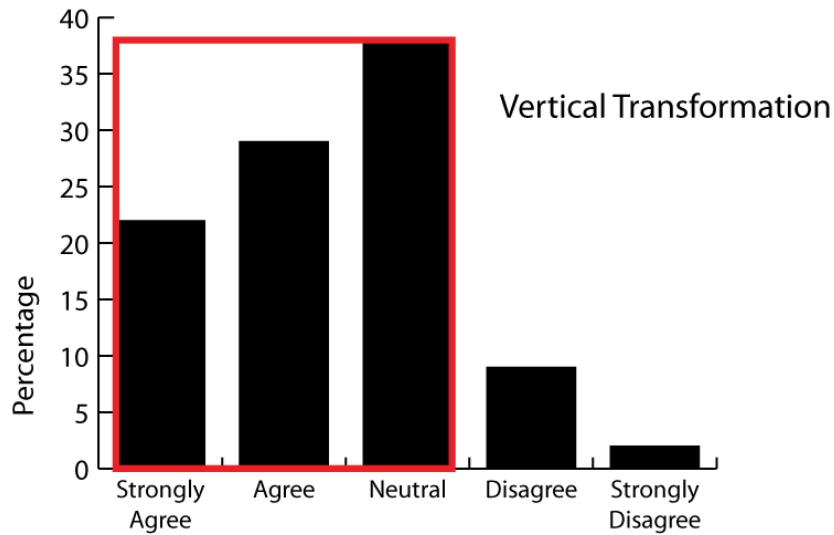


Figure 7.58 Model Making is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Results indicated that the use of model making might lead to the embodiment of commitment (Figure 7.59: strongly agree 33%, agree 45%). Attitudes were also positive in terms of the tool's ability to communicate design intent to others (Figure 7.60: strongly agree 41%, agree 28%):

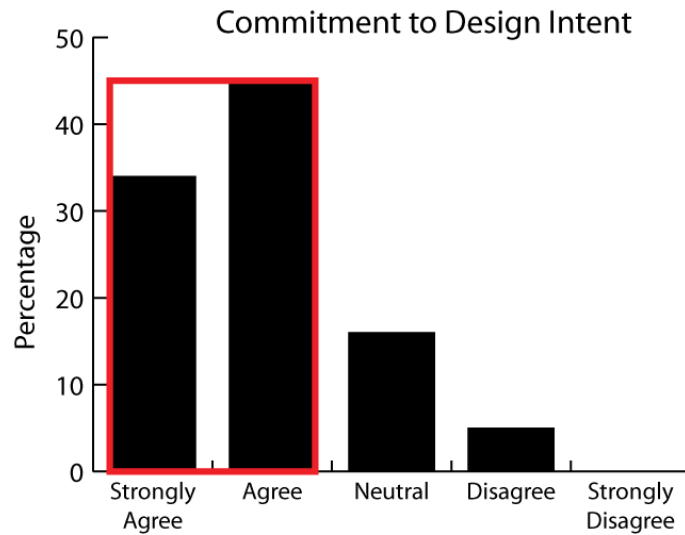


Figure 7.59 Model Making communicates a high level of commitment
(UTC: Level of commitment)

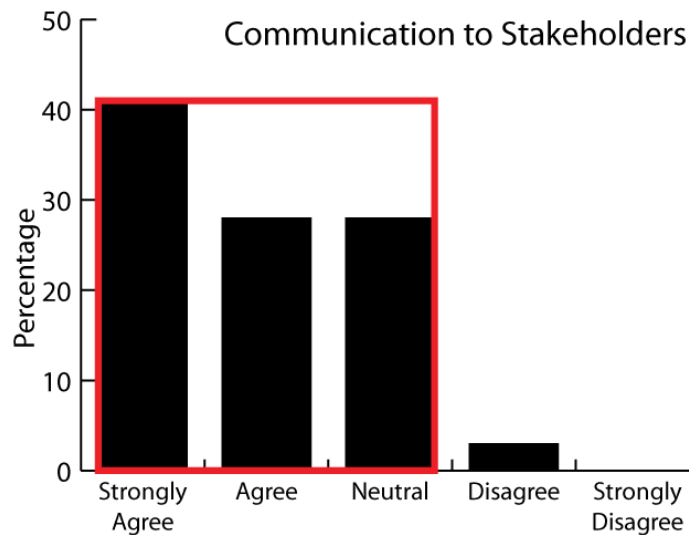


Figure 7.60 Model Making is useful for communicating intentions to others
(UTC: Mode of Communication)

Finally, a majority of practitioner responded with strongly agreed (35%) or agreed (30%) when asked of model making's effectiveness in support of reflection in action, although a further 27% registered a neutral response (Figure 7.61):

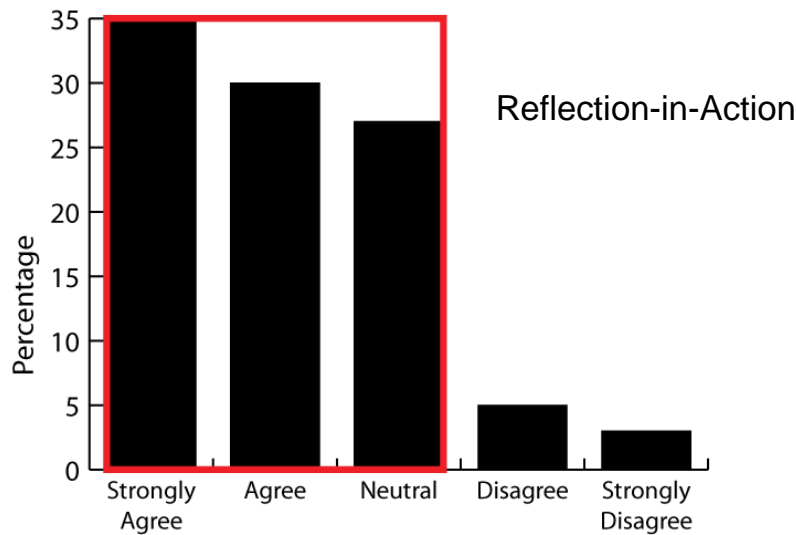


Figure 7.61 Model Making aids reflection and the generation of ideas
(UTC: Mode of Communication)

As with digital 3D CAD tools, results indicated largely positive practitioner attitudes towards model making tools across all 8 Likert-scale questions. However, the results also suggested a degree of uncertainty within the sample group, as indicated by higher neutral responses. It may be, as the literature suggests, that traditional handmade model making processes are becoming increasingly obsolete, with the exception of concept and sketch modelling processes during conceptual design. As the practitioners no longer tending to use conventional models they registered neutral responses. This was also suggested in the interview study, see Chapter 8.

7.3.9 Rapid Prototyping Tools

As with model making tools, responses to rapid prototyping tools (Zcorp's SLA and SLS prototyping processes) indicated positive attitudes towards the UTCs associated with convergent detail design (agreement, 56% and strong agreement, 33%, the tool's ability to support detailed design embodiment (Figure 7.62):

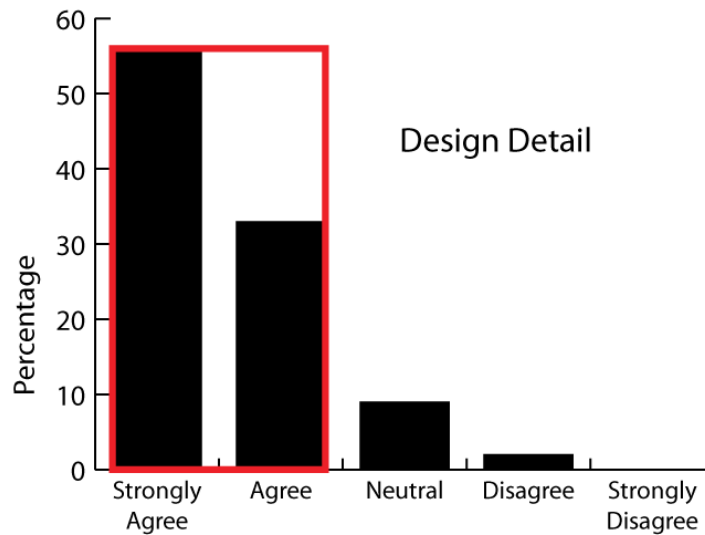


Figure 7.62 Rapid prototyping is useful in representing design detail (UTC: Level of Detail)

Practitioners also agreed (53%) or agreed strongly (21%) that rapid prototyping was effective in the embodiment of creative form, (Figure 7.63):

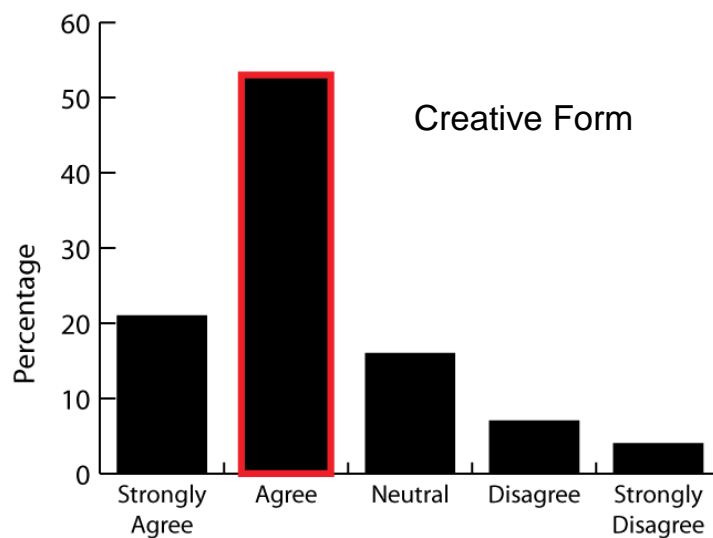


Figure 7.63 Rapid prototyping is useful for representing artistic/creative form (UTC: Level of Detail)

The ability of rapid prototyping to embody design intent unambiguously (Figure 7.64) was also rated positively by the practitioners (strongly agree 54%, agree 32%):

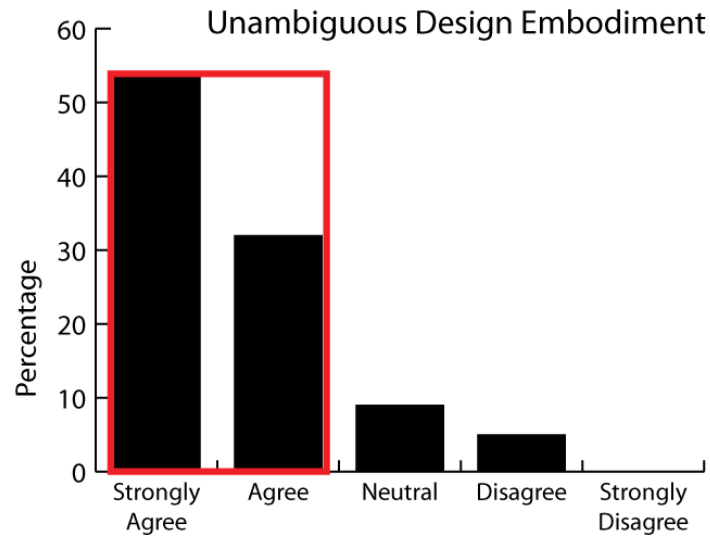


Figure 7.64 Rapid prototyping is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

The responses indicated positive attitudes towards the tool's ability to support communication with others (Figure 7.65), with 72% of respondents' registering stronger agreement:

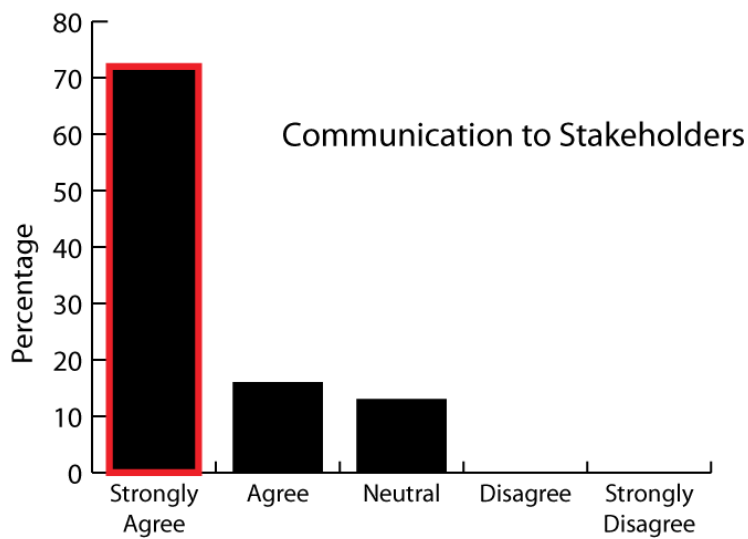


Figure 7.65 Rapid prototyping is useful for communicating intentions to others (UTC: Mode of communication)

Responses to other questions, received a more mixed reaction from the sample group. Although the results suggest positive attitudes towards rapid prototyping's ability to support vertical transformations (Figure 7.66), the findings also indicated some disagreement within the sample:

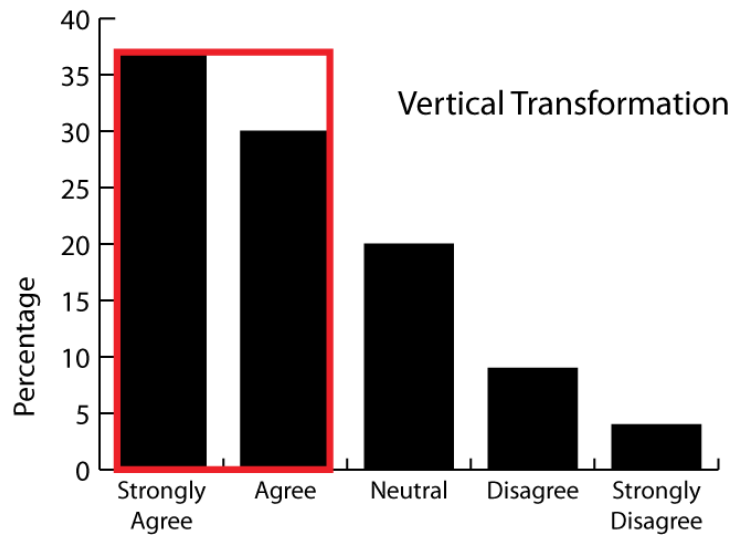


Figure 7.66 Rapid prototyping is useful for design work on variations of the same design idea (UTC: Transformational Ability)

Responses across the sample were also varied in terms of rapid prototyping's ability to support lateral transformations (Figure 7.67):

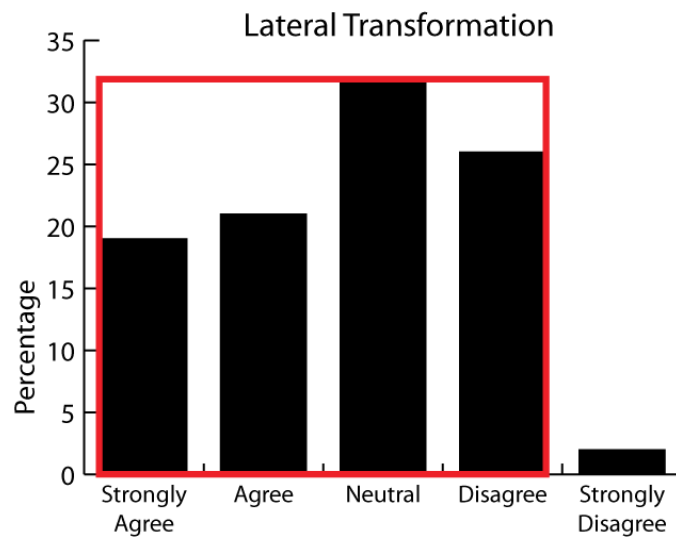


Figure 7.67 Rapid prototyping is useful for design work that moves easily between ideas (UTC: Transformational Ability)

Results for the question relating to reflection-in-action, were also mixed (Figure 7.68):

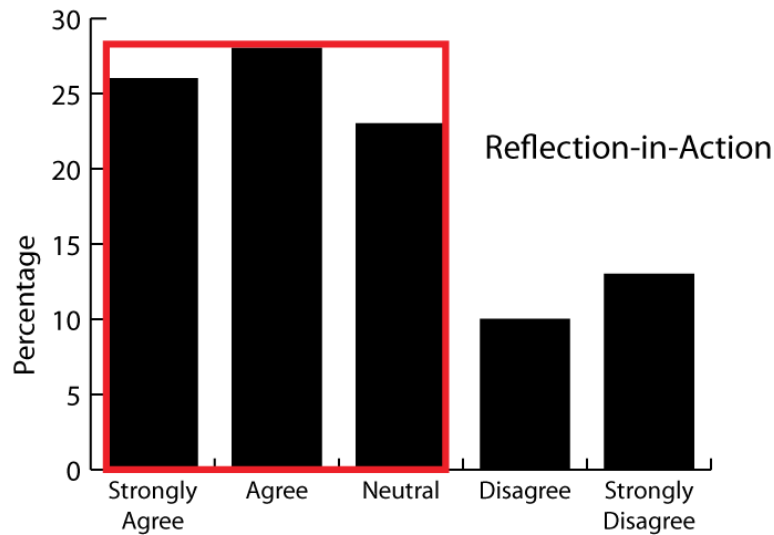


Figure 7.68 Rapid prototyping aids reflection and the generation of ideas
(UTC: Mode of Communication)

Survey findings relating to attitudes towards rapid prototyping appeared to be intuitive. That is to say that rapid prototyping tools, often cited as used during detail design, were seen as effective in the embodiment of detailed design intentions that were unambiguous, suggested commitment to design intent and were able to communicate intention to other stakeholders. However, rapid prototyping's ability to support lateral transformations, as well as reflection-in-action, showed differences in attitudes across the sample group. This could indicate the different approaches taken to the tool's use, with some practitioners using the tool to confirm and converge design proposal(s), others taking a more divergent, iterative approaches to the tool's use (see also Chapter 8).

7.3.10 2D CAD Tools

A majority of practitioners rated 2D CAD tools (engineering drawing and drafting software) as effective in the embodiment of design detail (Figure 7.69):

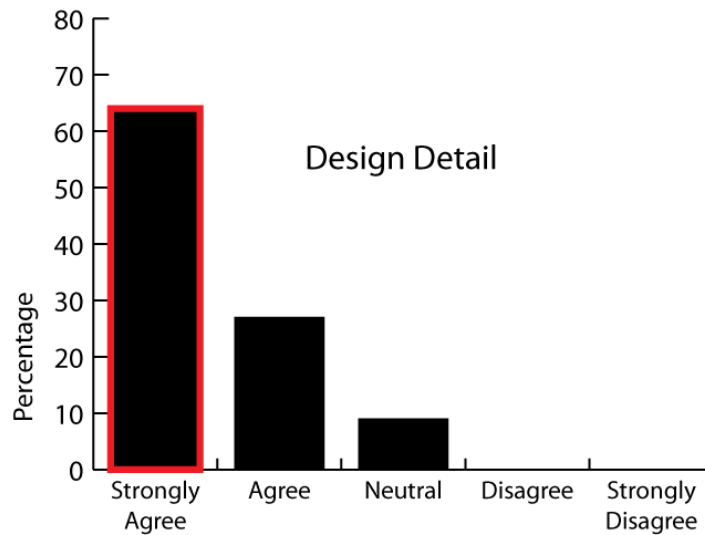


Figure 7.69 2D CAD is useful for representing design detail
(UTC: Level of Detail)

This was in contrast to the tool's effectiveness in supporting the representation of creative form (Figure 7.70), where 11% strongly disagreed and 36% disagreed about the tool's effectiveness:

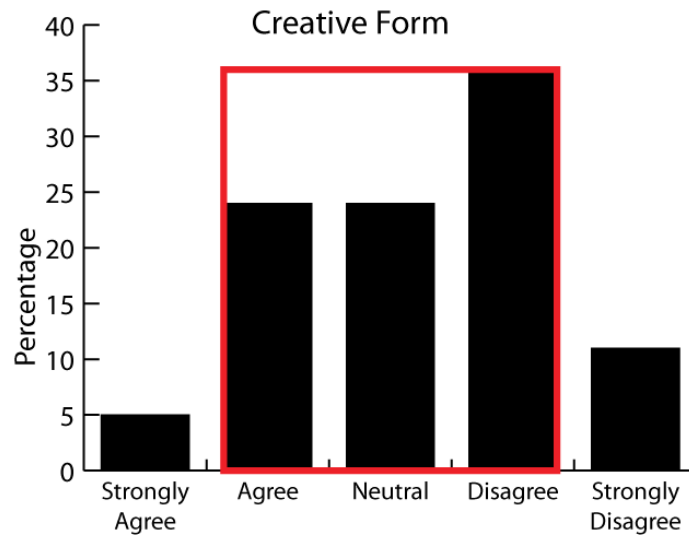


Figure 7.70 2D CAD is useful for representing artistic/creative form
(UTC: Level of Detail)

The sample also registered agreement or strong agreement in terms of the tool's ability to embody design intent in an unambiguous manner (Figure 7.71):

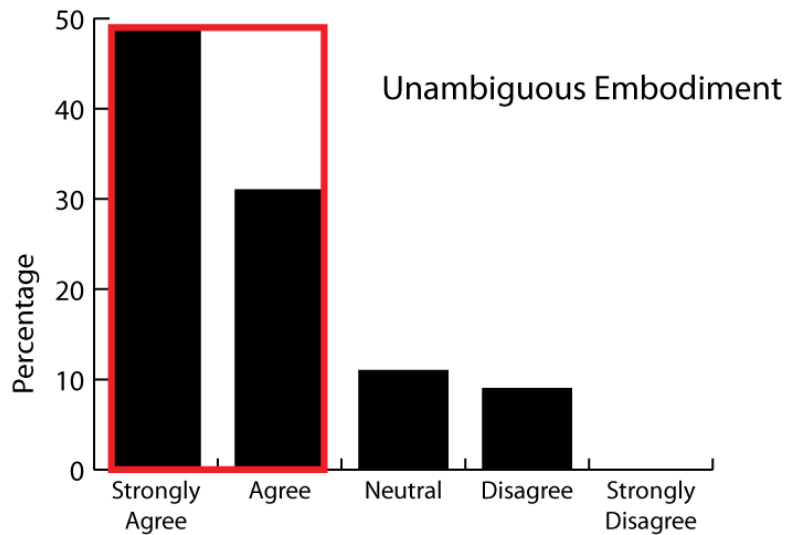


Figure 7.71 2D CAD is useful for representing ideas unambiguously (UTC: Level of Ambiguity)

Results relating to attitudes towards the tool's communication of commitment to design intent (Figure 7.72) indicated that practitioners considered design embodiment through 2D CAD tools as characterised by the committed nature of embodiment:

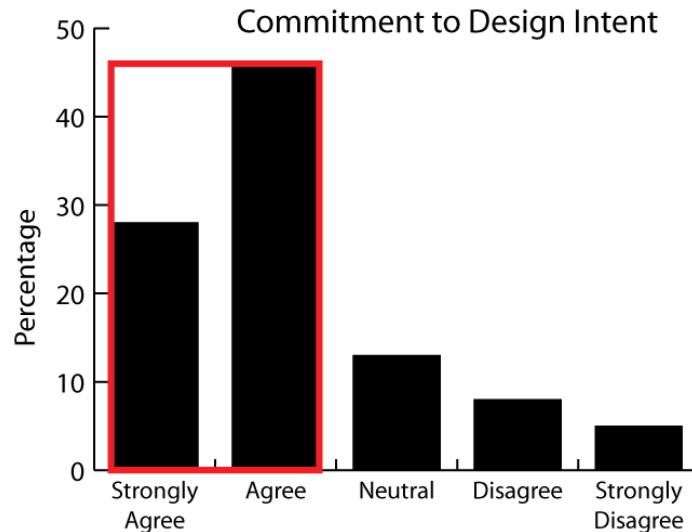


Figure 7.72 2D CAD communicates a high level of commitment (UTC: Level of Commitment)

In terms of 2D CAD's ability to support lateral (Figure 7.73) and vertical (Figure 7.74) transformations, although the weighting of response was positive, responses were somewhat mixed:

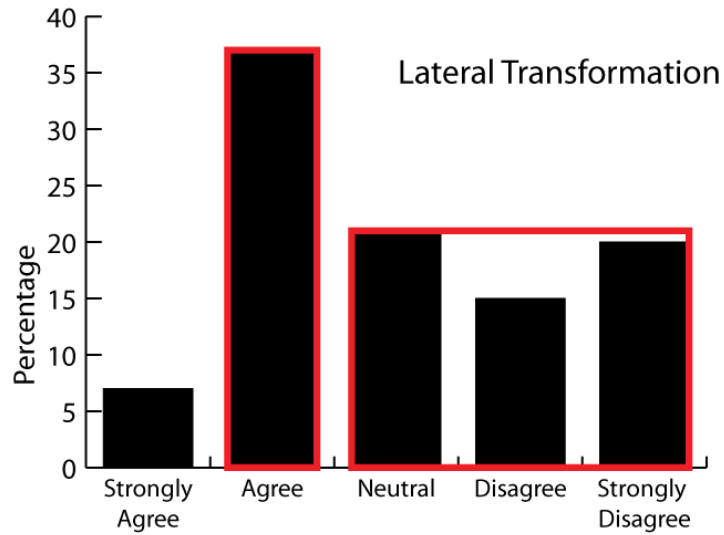


Figure 7.73 2D CAD is useful for design work that moves easily between ideas (UTC: Transformational Ability)

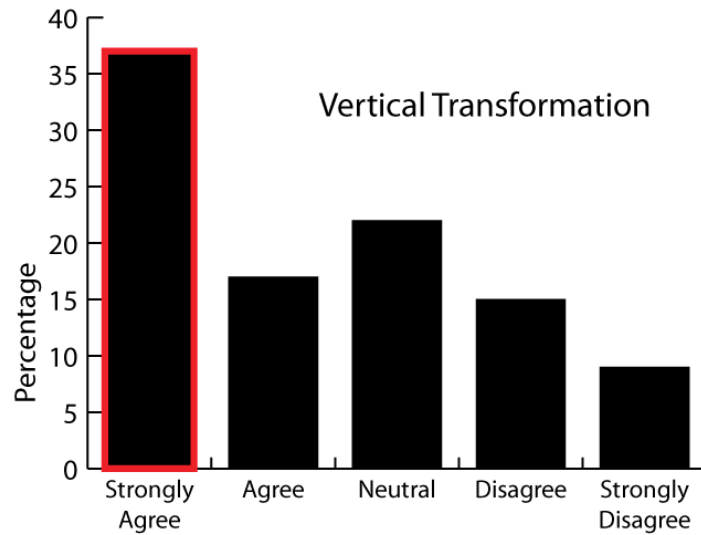


Figure 7.74 2D CAD is useful for design work on variations of the same design idea (UTC: Transformational Ability)

In terms of lateral transformations, 15% disagreed and 20% strongly disagreed that 2D CAD was characterised by its ability to move from one design idea to another. Disagreement towards vertical transformation was less pronounced (15% disagreement and 9% strong disagreement). This may suggest that practitioners consider 2D CAD to be more effective in a convergence of design activity.

Finally, practitioners registered mixed responses towards 2D CAD's ability to communicate design intent to others (Figure 7.75) and be used for reflective design activity (Figure 7.76):

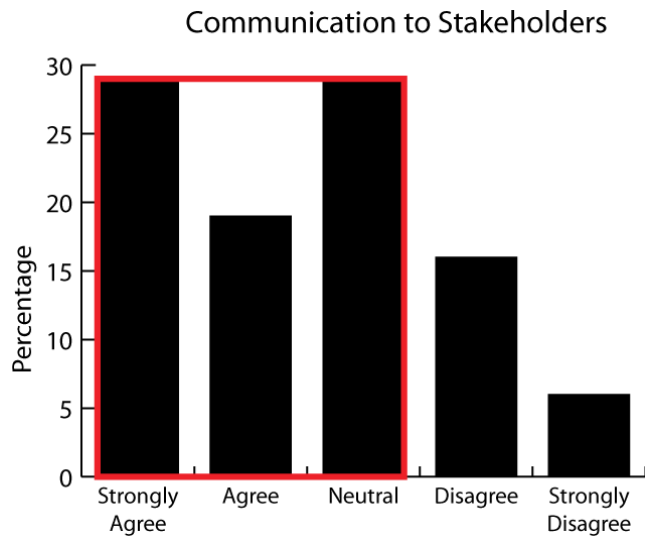


Figure 7.75 2D CAD is useful for communicating intentions to others
(UTC: Mode of Communication)

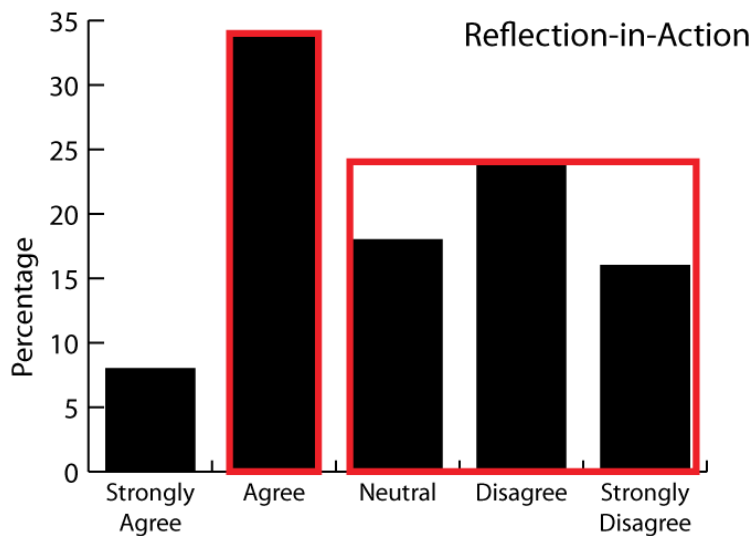


Figure 7.76 2D CAD aids reflection and the generation of ideas
(UTC: Mode of communication)

These results may again indicate the idiosyncratic use of the design tool in the variety of responses. This use may be tempered by the affording characteristics of the design tool. 2D CAD's tendency to be rated more positively in terms of vertical transformation compared to lateral: design detail as opposed to creative form.

The survey results were explored in terms of attitudes towards design tools and the types of design embodiments they support. Taken together, the results appear to indicate a relationship between the implicit character of the design tools and the ways this character allows certain kinds of embodiment to be made. The character of a tool has an influence upon the types of embodiments made and so the nature of design activity. However, results also suggested disagreement and contradictions within the sample group, with a number of mixed responses to the 8 Likert scale questions across the 10 design tools, as seen in responses to the tools' ability to support embodiment of creative form or communication to others. This could indicate differences in attitudes towards tools, suggesting the practitioner's own influence on tool use. This use informs how the design tool's implicit characteristics are seen and so manipulated to achieve the intentions of design activity.

Moreover, designers often registered confounding responses to the UTCs of the design tools. Evidence of this was seen in attitudes towards the tools' ability to support lateral and vertical transformations; the embodiment of design detail and creative form or unambiguity in embodiment. For example, when asked of conventional graphics tool's ability to support unambiguous embodiment, responses were mixed across the sample group (see Figure 7.39). This was also true for sketch modelling's ability to support design detail (Figure 7.19). These results suggested the limitations of understanding tool use in terms of the UTCs and how the UTCs relate to concept, development and detail design together with the influence of the tool-in-hane. The findings have indicated the use of tools is also critically influenced by the designer's own working methods and approach to tool use.

7.4 Designer Influence and Tool use

The previous section explored survey results in terms of relationships between design tool and object embodiment. This section presents results to further explore the designer's influence upon tool use (Figure 7.77):

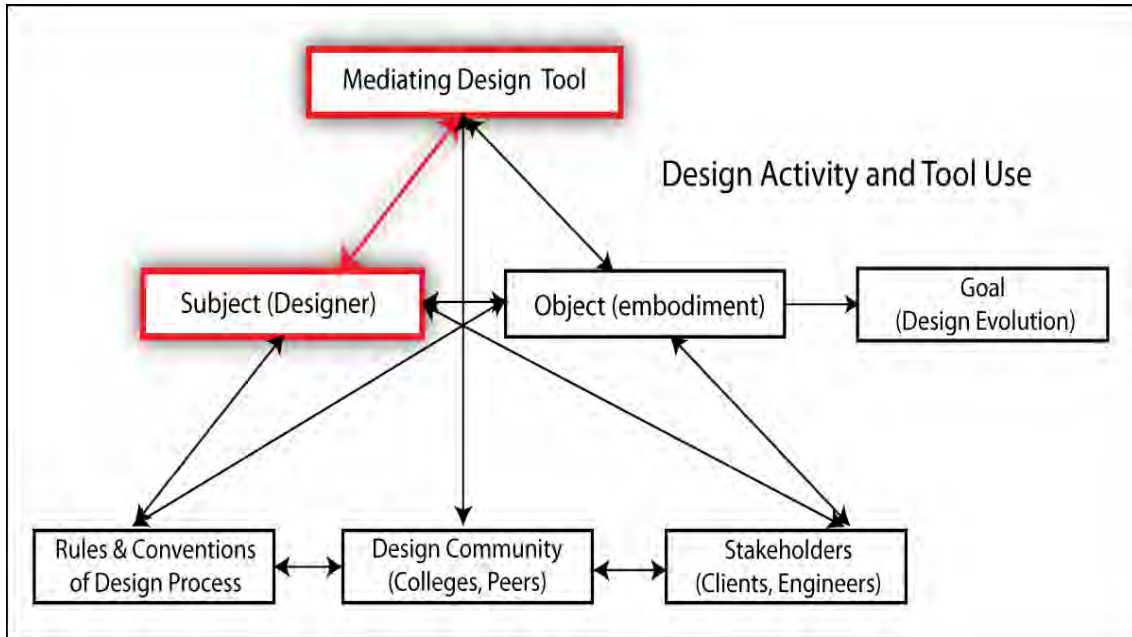


Figure 7.77 Relationship between mediating design tool and design practitioner

In order to investigate this relationship the survey results for the sample of practicing designers and students sample were compared (Chapter 6). The objective was to investigate how design expertise might influence the designer's attitudes towards tool use during design activity. As before, results relating to each of the 10 tools, categorised in the taxonomy, are presented in turn, with charts illustrating the survey results. Within each chart, practitioner results are indicated in black, students in grey. A first chart relating to each of the tools shows results for the 8 Likert-scale questions together. Along the vertical axis, mean scores are used to measure practitioner (Black) and student (Grey) responses to each question (mean: total of coded responses divided by number of respondents (see Chapter 6 coding and analysis section). Along the horizontal axis the 8 Likert-scale questions are presented (see Figure 7.78).

Subsequent bar charts are then used to present any significant differences between the two sample groups as illustrated by the first chart. Along the vertical axis, in these subsequent charts, responses are measured as percentages (percentage of total response to each of the 5 items on the Likert-scale, see Chapter 6). The horizontal axis presents the 5 items used in the Likert-scale question. In this way, the first chart provides an overview of responses to the 8 questions. The subsequent charts then present results relating to 1 of the 8 questions, with significant differences in responses illustrated further.

7.4.1 Hand Sketching Tools

Figure 7.78 shows the survey results for practitioner and student responses to the 8 Likert-scale questions relating to the design tool hand sketching:

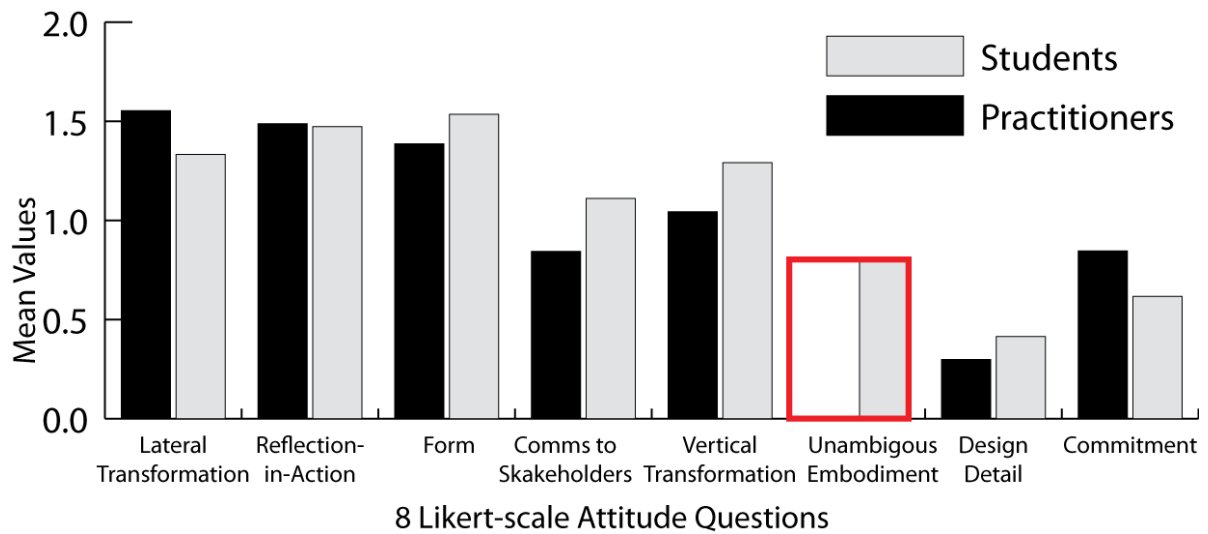


Figure 7.78 Responses to 8 attitude questions on the character of hand sketching tools

Results suggested practitioners and students held different attitudes towards sketching's ability to support ambiguity in design embodiment, with practitioners less likely to see sketching as effective in support of unambiguous embodiment compared to the student sample. As a mean score, practitioner responses measured [0] with a student mean of [0.8]. Results showed similar mean values across the remaining attitude questions (Figure 7.78).

Figure 7.79 illustrates practitioner and student responses to sketching's ability to support unambiguous embodiment:

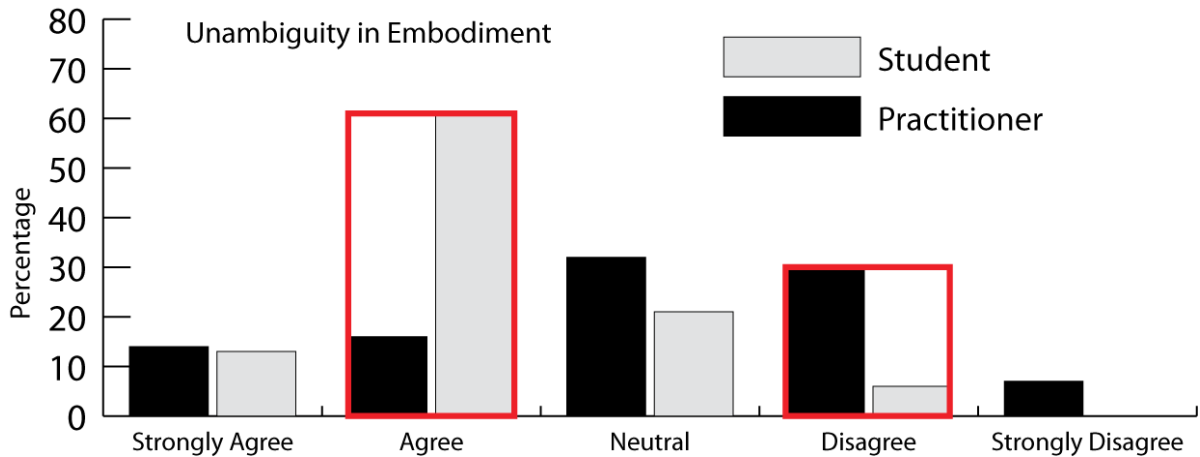


Figure 7.79 Hand sketching is useful for representing design ideas in an unambiguous way

The majority of student designers indicated agreement when asked about sketching’s ability to support unambiguous design embodiment. This contrasted with practitioners who tended to register neutral or disagree. These findings indicated different attitudes between designers with more or less experience of practice. The students may have a greater tendency towards unambiguity in design embodiment through sketching tools, compared to the practitioners’ more ambiguous approach. The positive responses to hand sketching across all 8 attitude questions bar unambiguous embodiment (mean scores of 0.00 practitioner, 0.80 student) was significant. This may indicate ambiguity is seen by the student sample as less desirable and be indicative of a different approach related to ambiguity in design embodiment.

7.4.2 Digital Sketching Tools

Figure 7.80 presents a comparison of practitioner and student results for the questions relating to digital sketching:

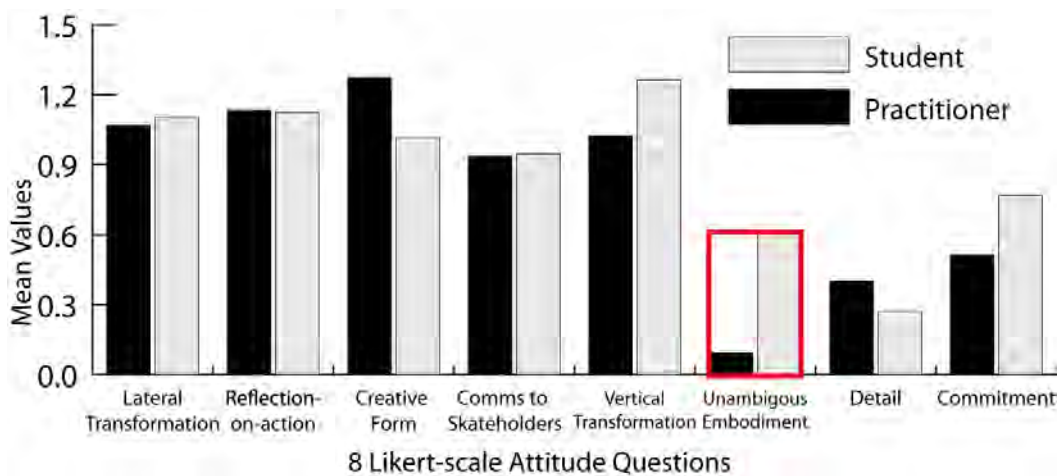


Figure 7.80: Responses to 8 attitude questions on the character of digital sketching tools

Similarly to hand sketching, practitioner and student responses were similar across all 8 Likert-scale questions bar one significant result; the ability of digital sketching to embody design ideas unambiguously (practitioner 0.09, students 0.61, Figure 7.80).

Figure 7.81 illustrates the distribution of responses, registered in terms of digital sketching's ability to support unambiguous embodiment:

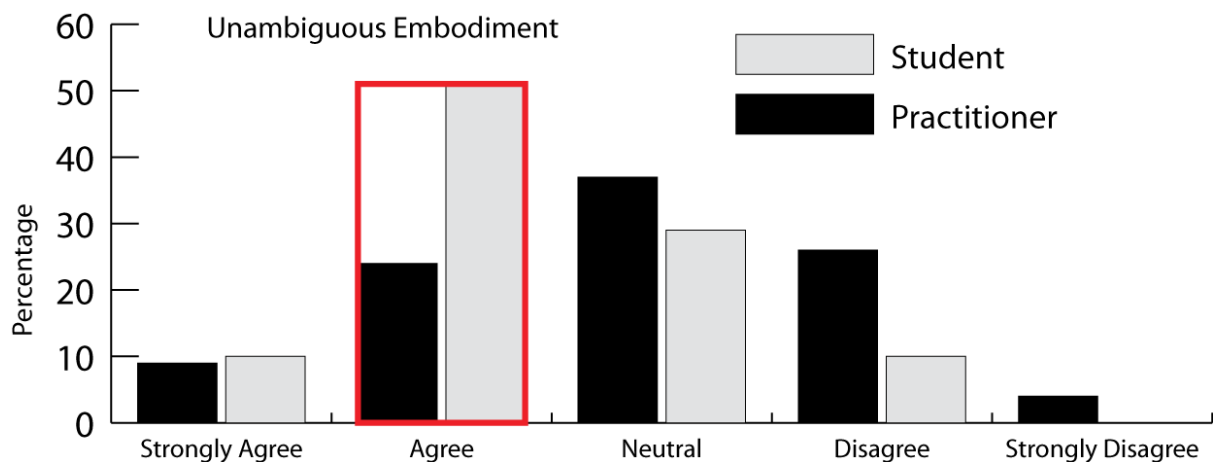


Figure 7.81: Digital sketching is useful for representing design ideas in an unambiguous way

In both hand and digital sketching, practitioner and student results indicated high mean scores across the 8 attitude questions with the exception of the tools' ability to support unambiguous embodiment. Also, student and practitioner responses showed a tendency to rate hand sketching more positively in terms of those UTCs associated with divergent concept design compared to digital sketching (lateral transformations, reflection-in-action, creative form). The reverse was true of digital sketching, which indicated a tendency to score the tool more highly in terms of those UTCs associated with convergent detail design practice (vertical transformations, commitment to design intent). This provided evidence to suggest perceptions of tool effectiveness differ in terms of digital vs. conventional sketching tools.

Given the different responses between samples in terms of the ability of digital and conventional sketching tools to support unambiguous embodiment, results might indicate the ways in which the designer's level of experience has implications for how sketching tools are used, and how this then has implications for the kinds of embodiments made; and the nature of design activity. These results appear to support the notion of a relationship between the practitioners, the use of the design tool and the kinds of embodiments made, as presented in the model of tool use in practice.

Ambiguity in design embodiment is influenced by both the tool-in-hand and the designer's approach to the tool's use.

7.4.3 Sketch Modelling Tools

Figure 7.82 illustrates student and practitioner responses to the 8 Likert scale questions relating to sketch modelling:

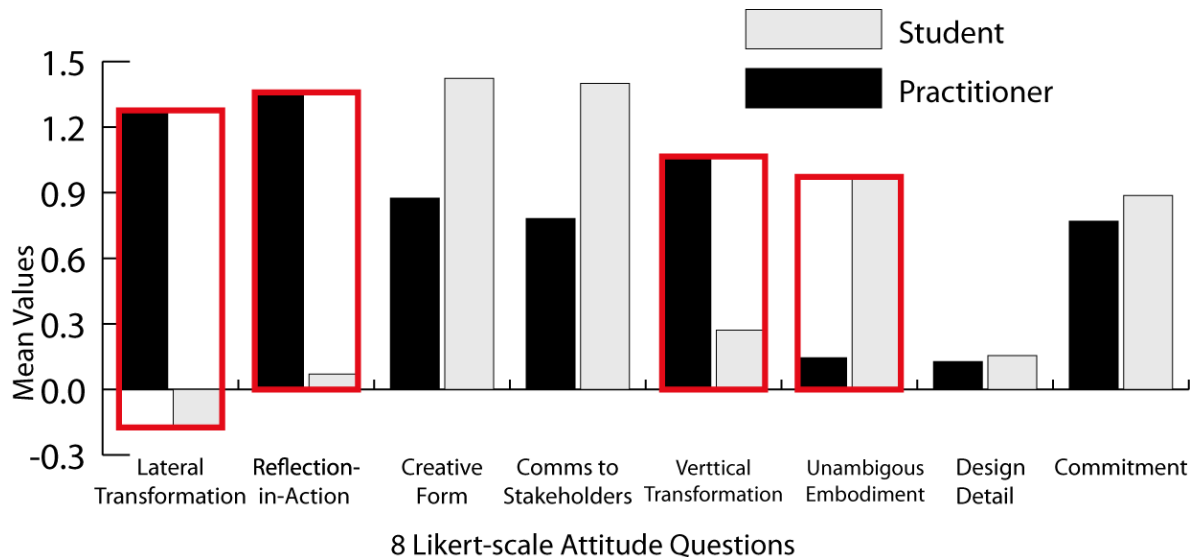


Figure 7.82 Responses to 8 attitude questions on the character of sketch modelling

Unlike results relating to hand and digital sketching tools (see 7.4.1 and 7.4.2), students and practitioners registered different responses across many of the 8 attitude questions (Figure 7.82). The greatest difference was seen in responses towards the tool's ability to support lateral transformations (student mean score: -0.17, practitioner mean: 1.28) and reflection-in-action (student mean: 0.07, practitioner: 1.36). Scores registered for sketch modelling's ability to support embodiment of creative form and communication of ideas to others also contrasted between the two samples, although to a lesser extent (creative form, practitioner: 0.88, student: 1.42; communication with others, practitioner 0.78, student: 1.40). The practitioner mean value related to the tool's ability to support vertical transformations was also greater (practitioner: 1.07, student: 0.27). Finally, the students' mean score for the tool's ability to embody design intentions unambiguously was considerably higher than that of the practitioners (student: 0.97, practitioners: 0.15). This reflected the previous results relating to student perceptions of ambiguity and sketching tools. It may be that students consider sketch modelling a more convergent tool of design embodiment compared to the practitioners. This also may reflect an underlying attitude in student practice that moves design towards convergent specification more quickly when using sketch modelling.

Figures 7.83 and 7.84 illustrate responses to the two Likert-scale questions asking designers of their attitudes towards sketch modelling's ability to support lateral and vertical transformations:

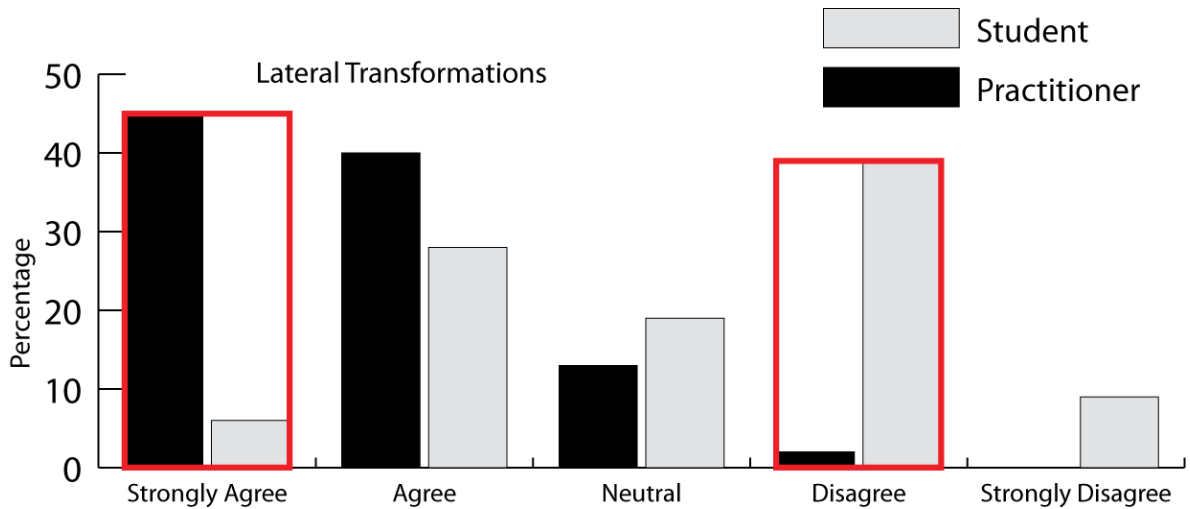


Figure 7.83 Sketch modelling is useful for design work that can move easily between design ideas (Lateral Transformations)

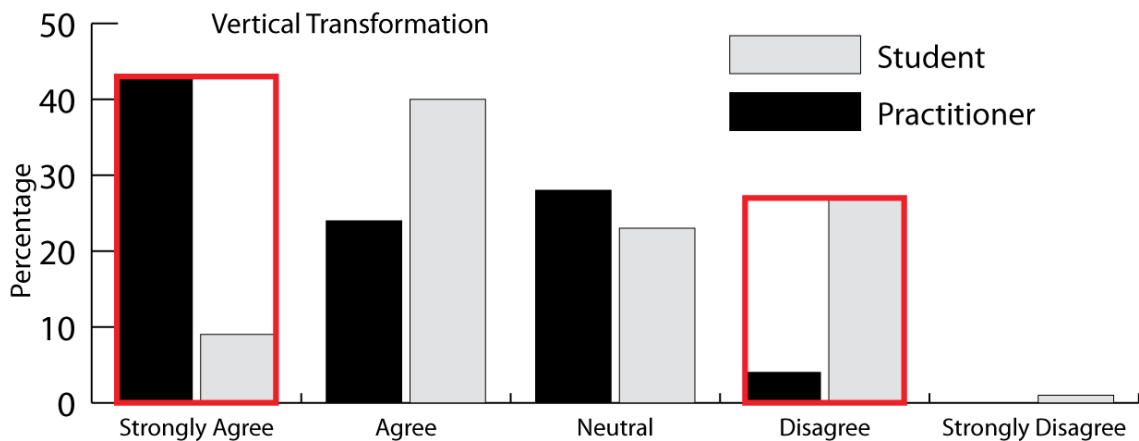


Figure 7.84 Sketch modelling is useful for design work on variations of the same design idea (Vertical Transformations)

Practicing designers registered agreement (40%) or strong agreement (45%) in terms of sketch modelling's ability to support lateral transformation in design embodiment (Figure 7.83), compared to the students who registered more mixed responses (28% in agreement, 39% in registering disagreement). This same pattern was seen in practitioner and student responses to the attitude question on the tool's ability to support vertical transformations (Figure 7.84). 43% of practitioners registered strong agreement with a further 24% in agreement and 28% neutral. The student results

indicated more mixed attitudes, with 40% in agreement but a further 27% in disagreement.

These results might indicate a tendency for some students to see sketch modelling as a tool less suited to transformations. However, practitioners see it as a tool effective in both lateral and vertical transformation and that design embodiment through sketch modelling is used for more explorative design activity by more experienced designers. If this is the case, it is an indication of how the designer's level of skill and experience influence the use of the design tool.

Figures 7.85 and 7.86 illustrate practitioner and student responses to questions of sketch modelling's ability to support reflection-in-action and unambiguous embodiment:

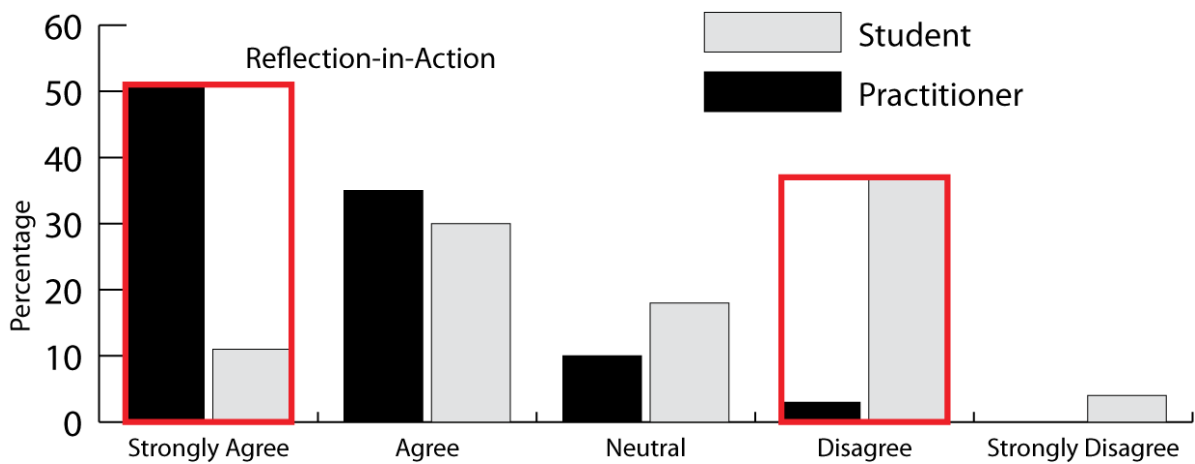


Figure 7.85 Sketch modelling aids reflection and the generation of design ideas

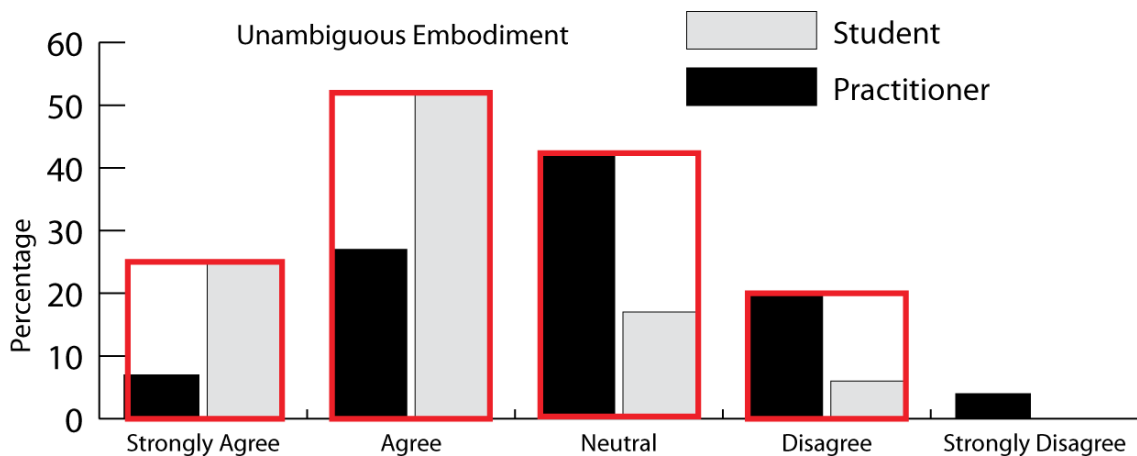


Figure 7.86 Sketch modelling is useful for representing design ideas in an unambiguous way

In terms of reflection-in-action (Figure 7.85), as with lateral and vertical transformations (see above), practitioner results showed a tendency to agree (35%) or strongly agree (51%). Results also indicated a tendency for practitioners to rate sketch modelling as effective in supporting reflection-in-action during embodiment. However, student results again suggested differences in attitudes within the student sample, with 30% agreeing and 35% in disagreement. In terms of sketch modelling's ability to support unambiguous embodiment, the results show mixed responses in both samples (Figure 7.86). Practitioners registered a neutral response (42%), with 27% in agreement and a further 20% disagreeing. Student results tended towards positivity (strongly agree 25%, agree 52%). Although there is some difference in student responses across the sample, findings suggest more positive attitudes towards sketch modelling's ability to support unambiguous embodiment compared to the practitioners.

Findings indicate that design students and practitioners might hold different attitudes towards sketch modelling and its use in support of studio practice. In terms of attitudes towards the UTCs associated with divergent concept design (lateral transformations, reflection-in-action), the findings indicated less agreement in the sample of students compared to practitioners. Results also suggested the student sample were more inclined to consider design embodiment through sketch modelling as unambiguous. Generally, findings indicated differences in approaches to and use of sketch modelling tools between the two sample groups. Evidence of this was seen in more positive student findings towards those characteristics associated with convergent detail design (vertical transformation, commitment to design intent, design detail), compared to the practitioners' tendency towards more positive attitudes towards UTCs associated with divergent concept design (lateral transformation, embodiment of creative/artistic form, reflection-in-action).

It might be that students are more inclined to consider sketch modelling as a tool for idea confirmation compared to practitioners, whose results indicated a more explorative, divergent approach. These results also serve as an indicator of the relationship between the influence of the designer's own attitudes and engagement with tools upon the embodiment of design intent. Engagement with tools seems to come as a result of existing approaches to design activity. For example, students tend to see the use of sketch modelling as a process of design convergence, and this is reflected in attitudes towards the design tools. In contrast, practitioners remain more open to divergent iteration and so remain more open when using design tools such as sketch modelling.

The use and character of design tools may be described as a result of both pre-existing working methods and the implicit character of the design tool. In terms of sketch modelling, student attitudes may reflect how experience influences approach and the use of certain tools, serving to compound pre-existing tendency towards earlier convergence and concept fixation.

7.4.4 3D Printing Tools

Figure 7.87 illustrates practitioner and student responses to 8 attitude questions relating to 3D printing tools:

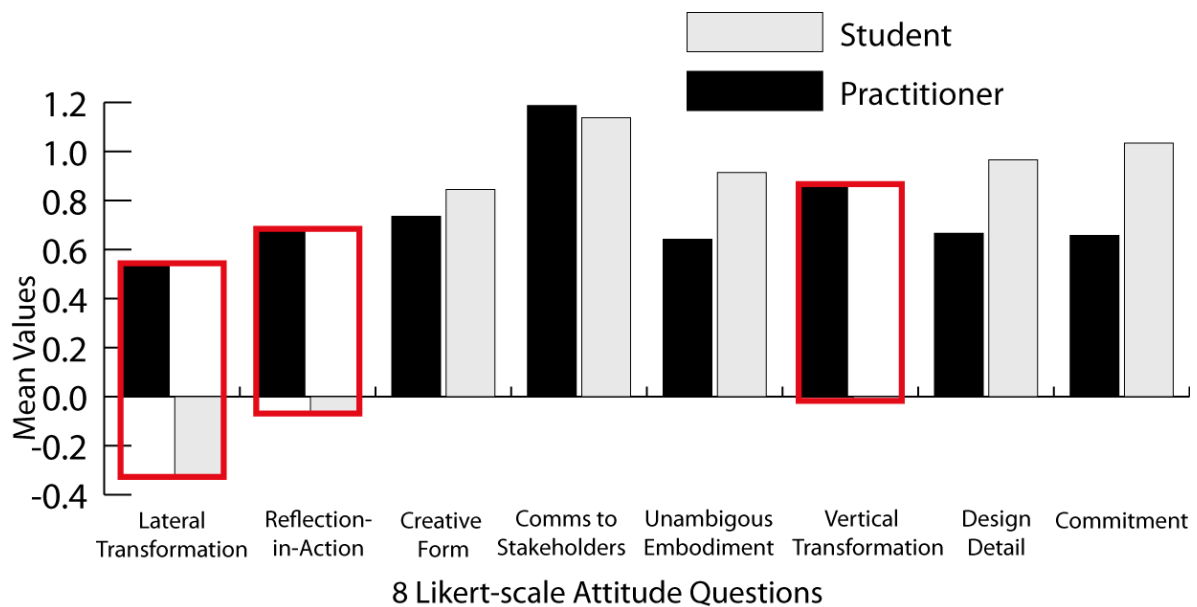


Figure 7.87 Responses to 8 attitude questions on the character of 3D printing tools

As with sketching modelling tools, differences in mean values (the sum coded response divided by the number of respondents) between the sample groups were identified in responses to the ability of 3D printing to support lateral transformations (practitioner: 0.54, student: -0.33), reflection-in-action (practitioner 0.68, student: -0.07) and the tool's use in vertical transformations (practitioner: 0.87, student -0.02).

Figure 7.88 illustrates practitioner and student responses towards 3D printing's ability to support lateral transformations.

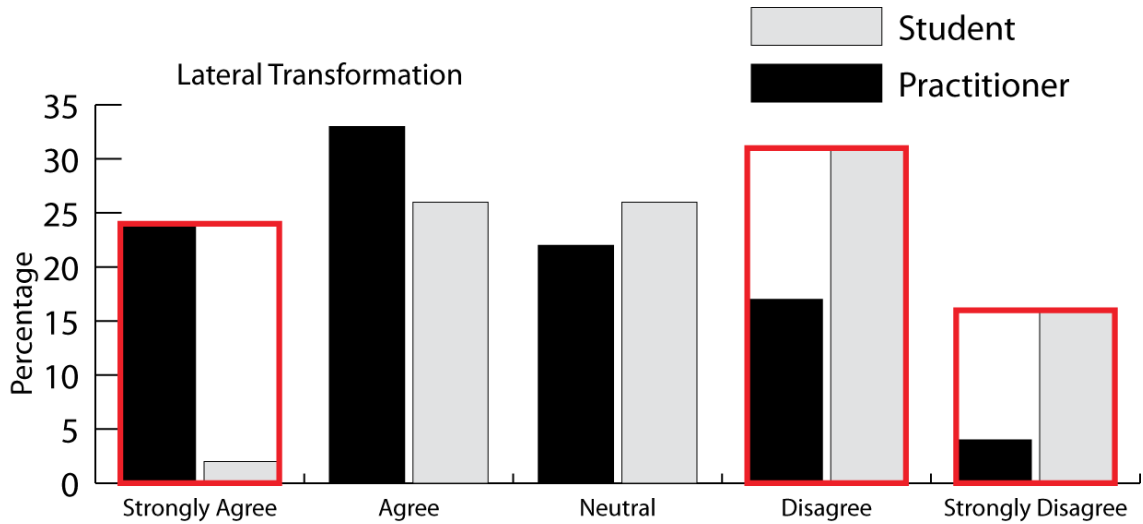


Figure 7.88 3D printing is useful for design work that can move easily between design ideas (Lateral Transformations)

The practitioners' tend towards agreement (33%) or strong agreement (24%) when responding to 3D printings ability to support lateral transformations. The student responses identified more negative attitudes within the sample group (agree 26%, neutral 26%, disagree 31% and strongly disagree 16%).

Figure 7.89 illustrates the results for student and practitioner responses to 3D printing's ability to support reflection-in-action:

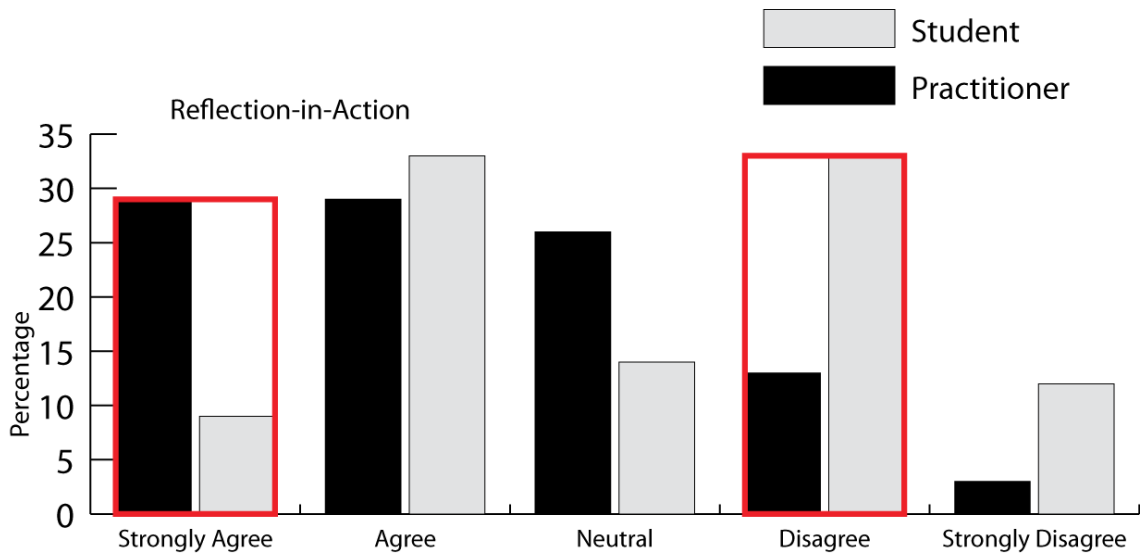


Figure 7.89 3D printing is useful for design work to aid reflection and the generation of design ideas

As with responses towards lateral transformations, results indicated a greater tendency for practitioners to register agreement or strong agreement (both 29%) in contrast to student responses, which were more mixed (agree: 33%, disagree 33%).

Figure 7.90 illustrates practitioner and student results of 3D printing's ability to support vertical transformations:

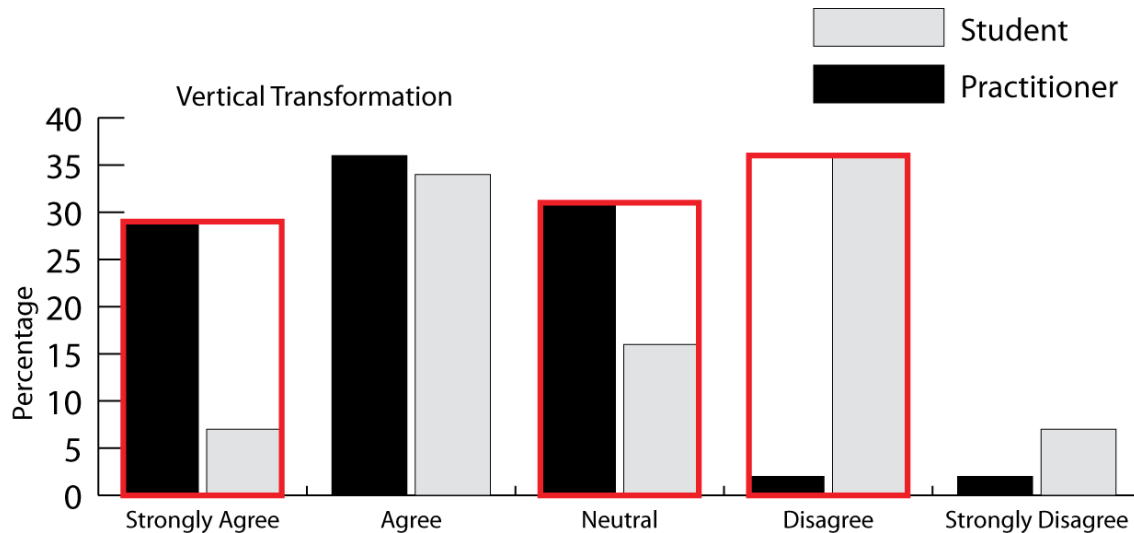


Figure 7.90 3D printing is useful for design work on variations of the same design idea
(Vertical Transformations)

Results indicate a tendency for practitioners to agree or agree strongly (36%, 29%). As with other differences in response between sample groups however, student results were mixed, with an approximately equal number registering agreement (34%) and disagreement (36%).

Responses to questions relating to the tool's ability to support transformations and reflection-in-actions indicated the differences in attitudes between the two sample groups. Results revealed greater uncertainty within the student sample with regards the tool's ability to support UTCs compared to the practitioners. As the UTCs reflection-in-action and transformation are often associated with divergent explorative design activity, these results may suggest that student designers perceive 3D printing to be a more convergent tool that is used to validate intent rather than iterate solution ideas. This may then be a reflection of the students' studio practice as it tends towards convergence with this tendency being compounded through the use of certain tools (see also 7.4.3, Sketch Modelling Tools).

In terms of the tools classified under concept design within the taxonomy, a difference was identified in attitudes towards hand and digital sketching's embodiment of

unambiguous design intent. Findings suggested that students were more likely to respond positively to the idea of unambiguous embodiment during sketching compared to practitioners. Responses to sketch modelling and 3D printing also identified differences between the samples. These differences were most noticeable in responses to the tools' ability to support both vertical and lateral transformations and reflection-in-action. Student responses were mixed, whereas practitioners tended to respond positively. It may be that this is indicative of student approaches to conceptual design practice that may be characterized as being more constrained and convergent than that of the practitioner sample. This might also be seen in their attitudes towards design tools, i.e. sketch modelling and 3D printing were less effective in supporting those UTCs often associated with divergent concept design. These findings help develop the notion of the subject practitioner as an influence upon the use of the tool-in-hand during design activity. The different approaches students and practitioners bring to studio practice and design activity influences the manipulation of tools in the embodiment of design intent. These Research findings have started to suggest the nature of these differences.

7.4.4 Digital Graphics Tools

The results for practitioner and student responses to the UTCs of design embodiment when using digital graphics tools (Adobe photoshop, Illustator) are shown in Figure 7.91:

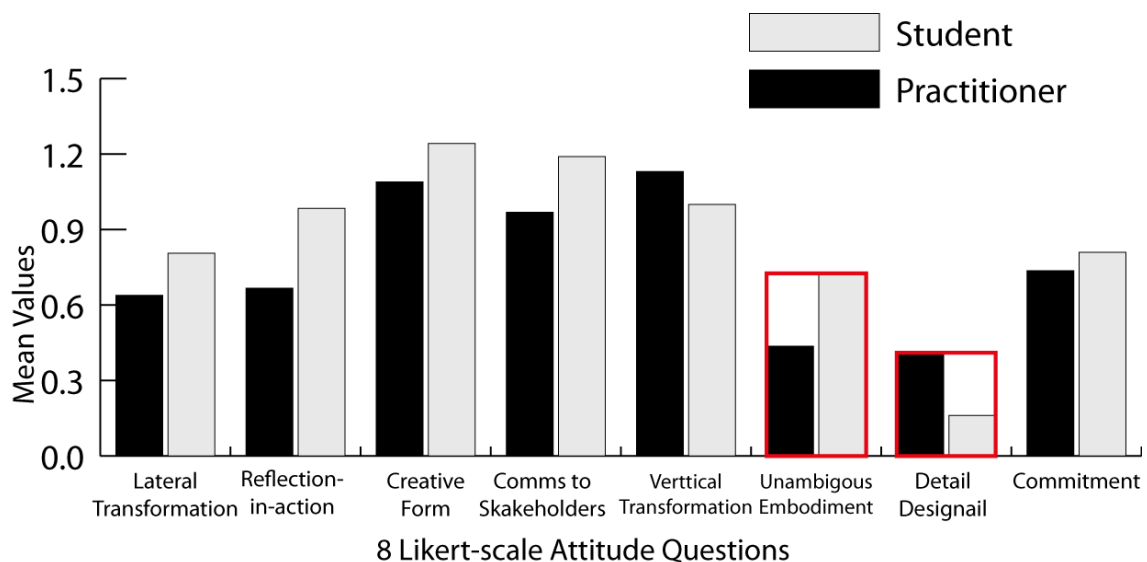


Figure 7.91 Responses to 8 attitude questions on the character of digital graphics tools

Unlike results relating to sketch modelling and 3D printing, there was little difference in student and practitioner responses to the 8 questions. Of the differences in mean values, the greatest disparity was seen in responses to the tool's ability to support the

embodiment of detail (practitioner: 0.41, students: 0.16, Figure 7.91) and unambiguous embodiment (practitioner: 0.45, students: 0.74).

Figure 7.92 illustrates results relating to the question of digital graphic tool's ability to support the embodiment of detail:

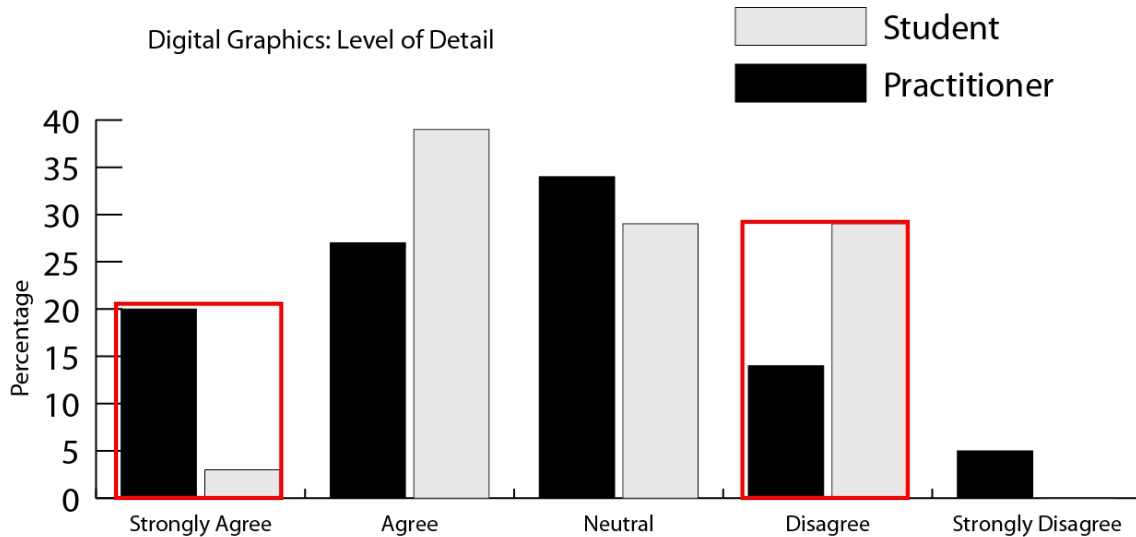


Figure 7.92 Digital graphics tools are useful for representing the engineering detail of design ideas

This chart showed that, as with results indicating differences in attitudes towards sketch modelling and 3D printing, practitioners were more positive in their responses with less variation within the sample (strongly agree 20%, agree 27% and neutral 34%). Student responses were mixed (agree 39%, neutral 29%, disagree 29%). This indicated the attitudes of respondents within the sample of students tended to confound more so than the sample of practitioners. As a sample group, although differences in response were seen, practitioner responses were less varied across the 5 items of the Likert-scale, compared to more mixed student responses.

7.4.5 Conventional Graphics Tools

As with digital graphics tools, Figure 7.93 illustrates responses across 8 attitude questions relating to conventional graphics tools (marker rendering techniques)

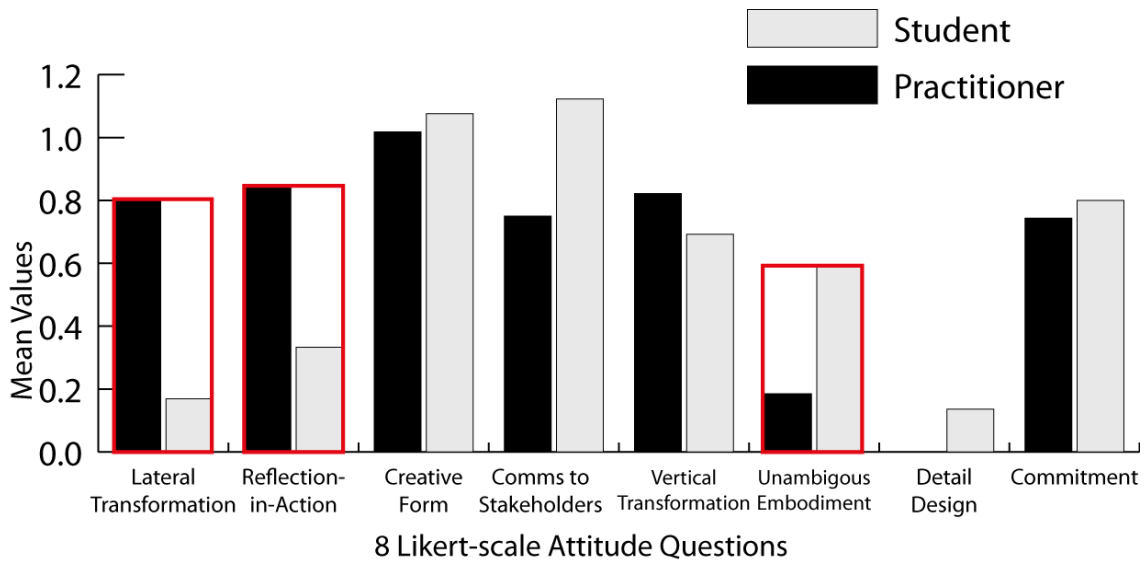


Figure 7.93 Responses to 8 attitude questions on the character of digital graphics tools

Some differences in response were seen in answers to questions relating to the tool's ability to support embodiment of detail and also unambiguous embodiment (0.19, 0.59 Figure 7.93). However, in a similar way to sketch modelling and 3D printing, considerable differences were registered in response to questions relating to the tool's ability to support both lateral transformations (0.80, 0.17) and reflection-in-action (0.85, 0.33).

Figures 7.94 and 7.95 illustrate the distribution of responses across the Likert-scales for questions 4 and 8 relating to lateral transformation and reflection-in-action:

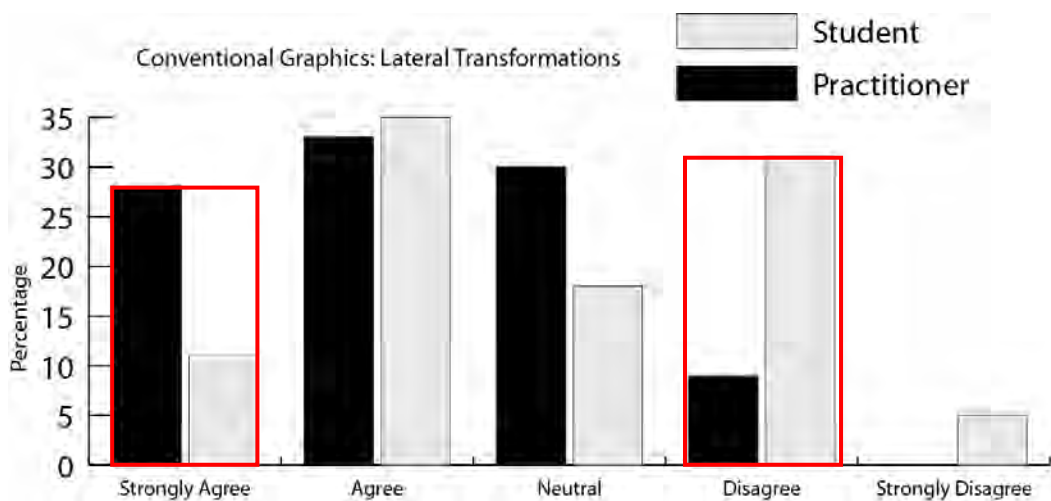


Figure 7.94 Conventional graphics tools are useful for design work that can move easily between design ideas (Lateral Transformations)

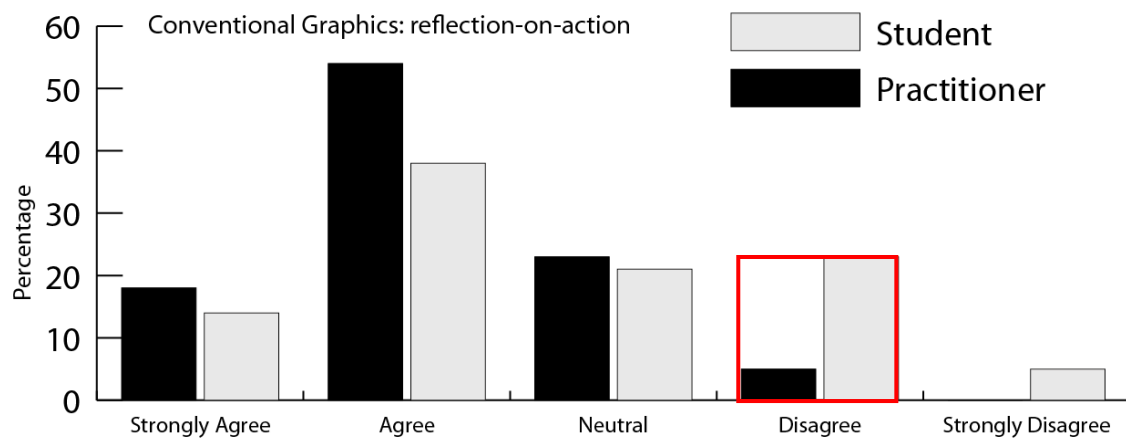


Figure 7.95 Conventional graphics tools are useful for design work that aids reflection and the generation of design ideas

Practitioner results indicated less variation between agreement and disagreement within the sample (Figures 7.94 & 7.95) and responses tended towards the positive left side of each Likert-scale. However, students tended to register responses that were spread between agreement and disagreement (Figures 7.94 & 7.95). This suggests that the sample of practitioner attitudes were more similar towards the tool's ability to support certain kinds of embodiment. The student sample appeared less in agreement, with respondents holding confounding attitudes. It may be that some students see the use of digital graphics tools as supporting design convergence, indicated through negative responses to the tool's ability to support those UTCs often associated with divergent conceptual design: lateral transformations and reflection-in-action. This again might be a result of an approach to practice that is more constrained, resulting in concept crystallisation sooner. An approach compounded through the use of conventional graphics tools.

Figure 7.96 illustrates results for practitioner and student responses to conventional graphics tools' ability to support unambiguous embodiment.

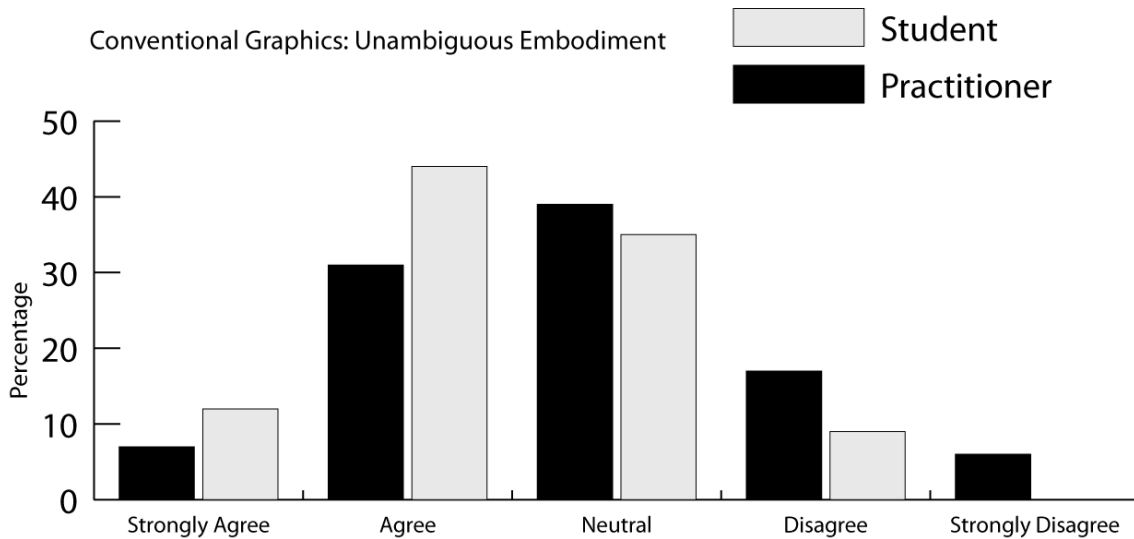


Figure 7.96 Conventional graphics tools are useful for representing design ideas in an unambiguous way

Results showed the practitioners registered marginally less positive responses in terms of the tool's ability to support the unambiguous embodiment of design intent compared to the student designers.

7.4.6 3D CAD Tools

Figure 7.97 illustrates responses to 8 questions relating to the character of 3D CAD:

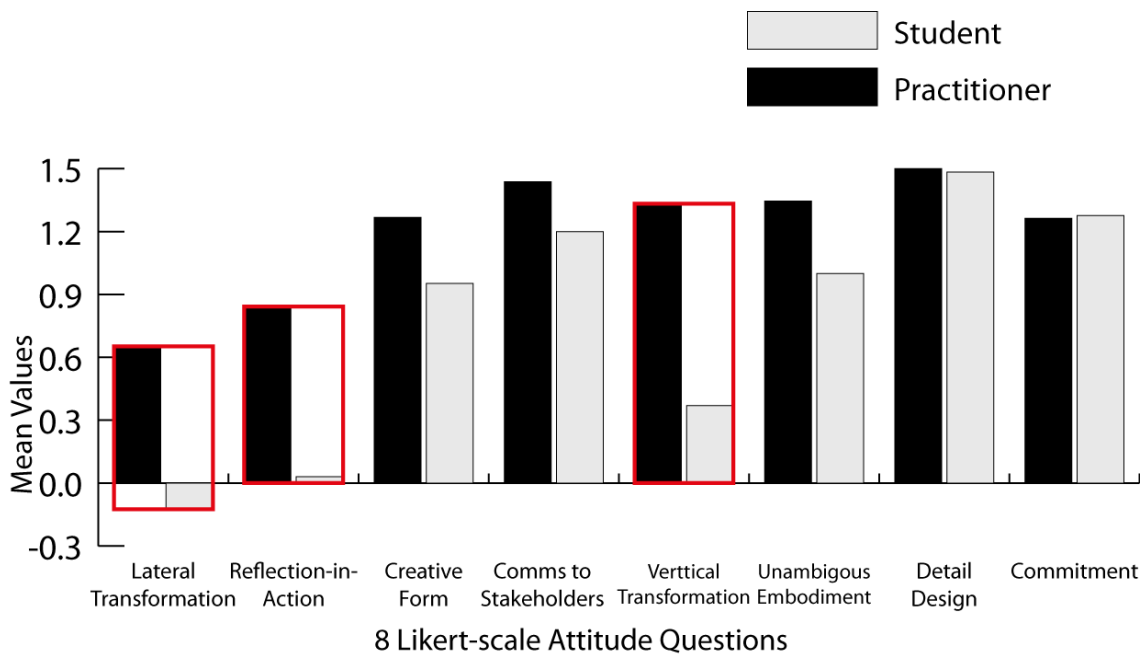


Figure 7.97 Responses to 8 attitude questions on the character of 3D CAD

As with digital and conventional graphics tools, differences in responses between sample groups was identified in results relating to 3D CAD's ability to support UTCs often associated with divergent concept design (lateral transformations, 0.65, -0.13 and reflection-in-action: 0.84, 0.03, Figure 7.97). Practitioners were more positive in their response to 3D CAD's ability to support vertical transformations (1.33, 0.37) which may suggest that the students consider the tool less suited to divergent explorative design.

Responses relating to lateral transformations (Question 4), vertical transformations (Question 8) and the tool's ability to support reflection-in-action (Question 5) are illustrated in Figures 7.98, 7.99 and 7.100:

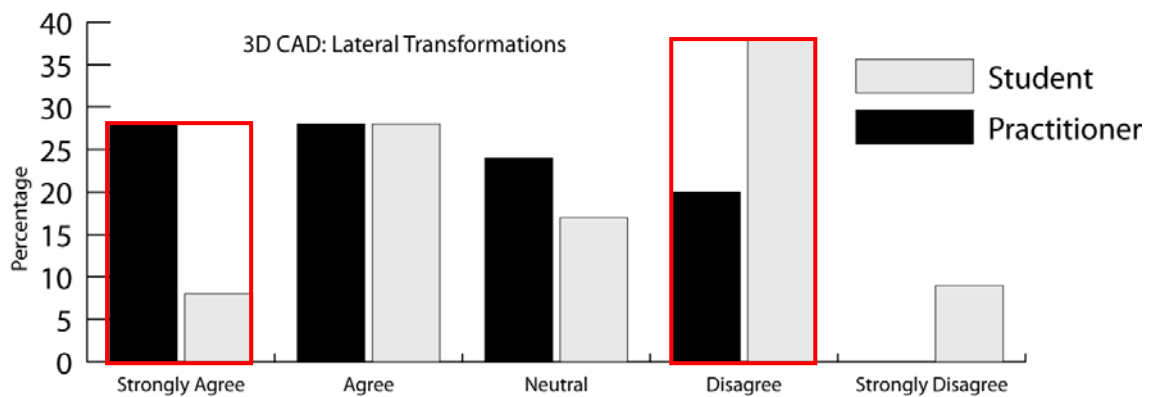


Figure 7.98 3D CAD is useful for design work that can move easily between design ideas (Lateral Transformations)

In terms of 3D CAD's ability to support lateral transformations, findings showed that practitioners tended to register more positive responses (strongly agree 28%, agree 28%) although a further 24% of responses were neutral, with 20% indicating disagreement. In contrast, the student sample registered a wider distribution of responses across the Likert scale (8%, 28%, 17%, 38%, 9%). This suggests the sample of students were less positive in their attitudes towards the ability of 3D CAD to support lateral transformations during embodiment. It may also suggest a greater difference in attitudes within the sample group compared with the attitudes of the practitioners. This difference was also seen in the student sample's distribution of responses to 3D CAD's ability to support reflection-in-action and vertical transformations (Figure 7.99):

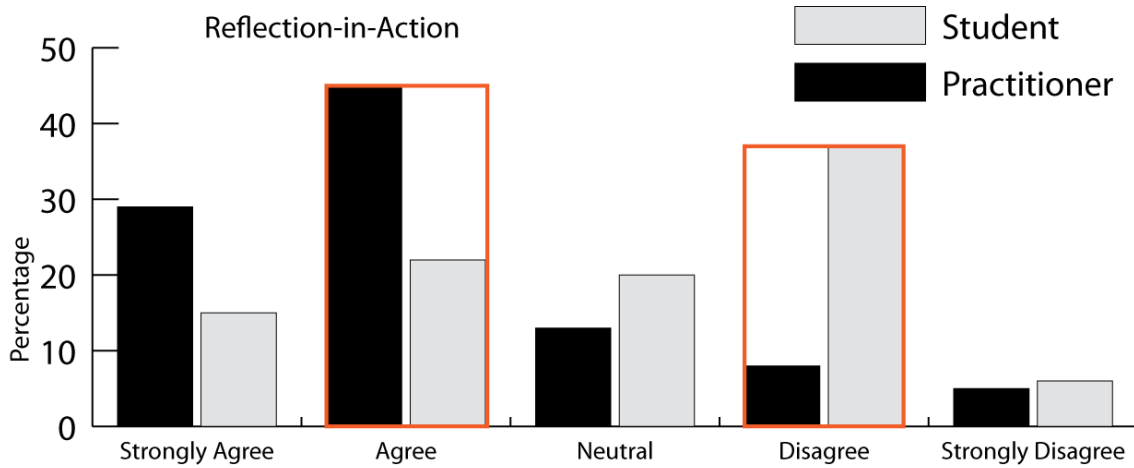


Figure 7.99 3D CAD is useful for design work that aids reflection and the generation of design ideas

In terms of reflection-in-action, results indicated a tendency for practitioners to consider 3D CAD as more effective (strongly agree 29%, agree 45%). This was in contrast to the distribution of student responses, with the largest percentage registered at disagree (37%, Figure 7.99). The same pattern was repeated in terms of 3D CAD’s ability to support vertical transformations (Question 5, Figure 7.100):

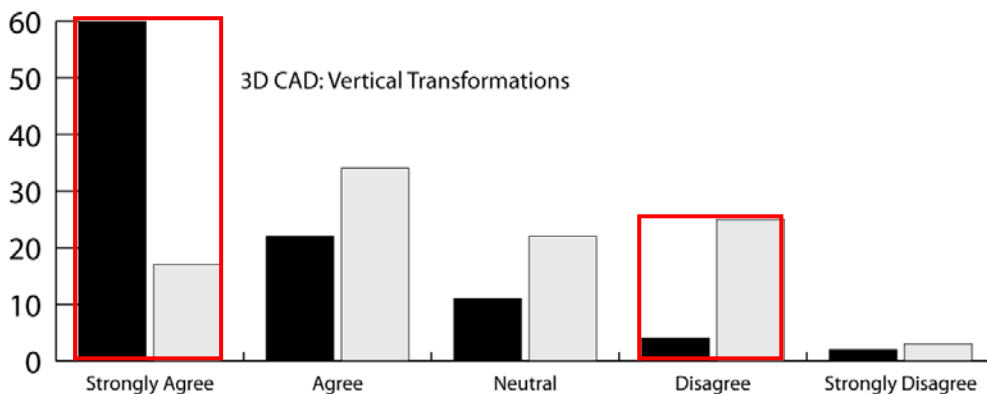


Figure 7.100 3D CAD is useful for design work on variations of the same design idea (Vertical Transformations)

Student responses were distributed across the scale, and had a tendency for practitioners to rate the tool more positively were identified in the results (strongly agree 60%, agree 22%, Figure 7.100).

These results indicated a difference in attitudes between the sample groups. Where differences were found, results suggested a wider distribution of student responses compared to more positive and less distributed practitioner attitudes. As with digital and

conventional graphics tools, sketch modelling and 3D printing, practitioner responses to 3D CAD indicated greater positivity towards its ability to support UTCs related to divergent and explorative design activity (lateral transformations, reflection-in-action). Responses to the tool's ability to support vertical transformations also differed, reflecting findings for other tools; sketch modelling and 3D printing. These findings indicate design experience as an influence on attitudes towards 3D CAD during studio practice. Results suggested what these differences might be in terms of UTCs and how they may relate to the designer's own approach to design activity and tool use. As with other tools, less experienced designers may tend towards convergence and concept fixation through the use of 3D CAD, as manifest in responses to the attitude questions. This may be both a reflection of pre-existing working methods and compounded through the use of individual design tools.

7.4.7 Conventional Model Making Tools

Practitioner and student responses towards the design tool conventional model making are illustrated in Figure 7.101.

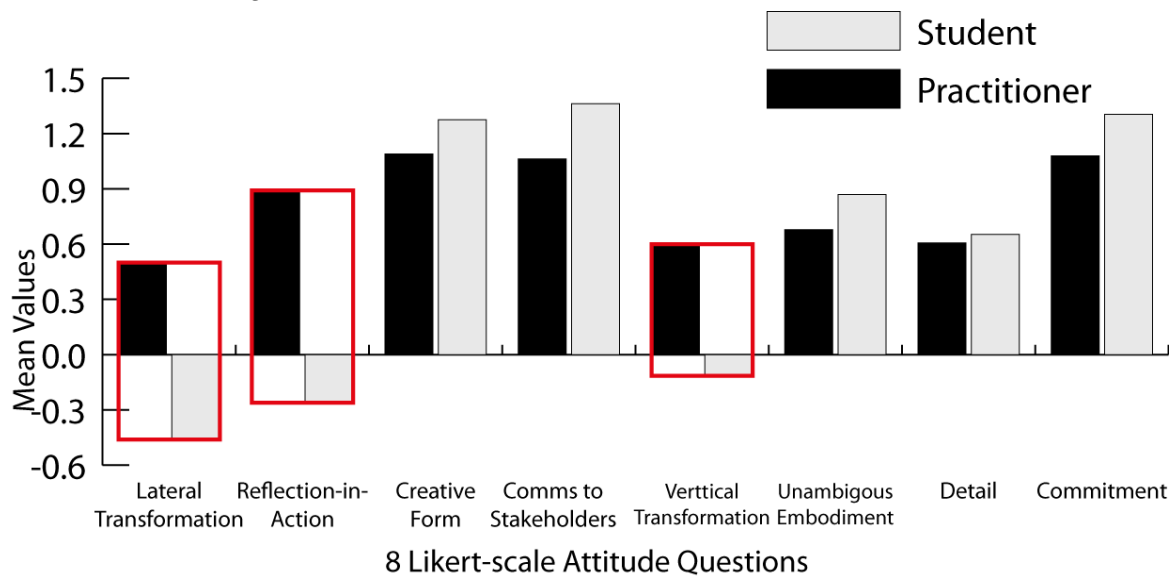


Figure 7.101 Responses to 8 attitude questions on the character of conventional model making

As with 3D CAD above, the most significant difference between the samples were seen in responses to model making's ability to support lateral transformations (0.50, -0.46), reflection-in-action (0.89, -0.26) and vertical transformations (0.60, -0.12). Again, those UTCs often associated with divergent conceptual design were rated more positively by practitioners compared to student designers.

Figures 7.102, 7.103 and 7.104 illustrate the distribution of responses across the Likert-scales for the three survey questions relating to lateral and vertical transformations (Questions 4 and 5) and reflection-in-action (Question 8).

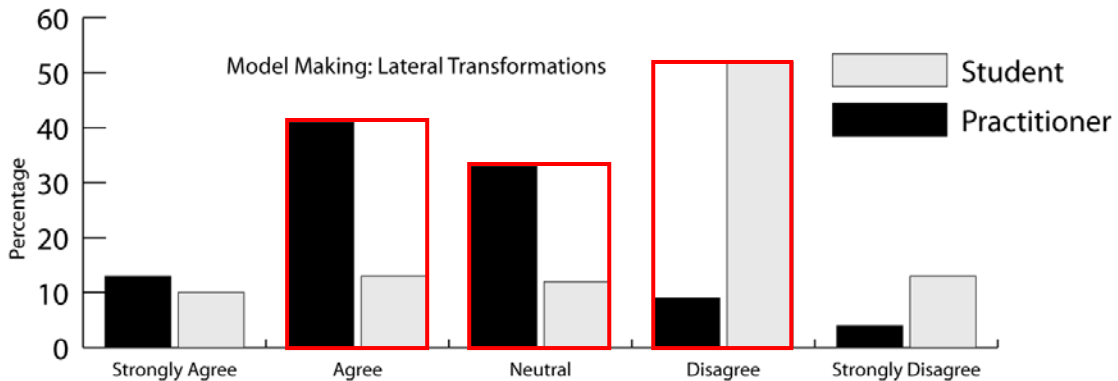


Figure 7.102 Model making is most useful for design work that can move easily between design ideas (Lateral Transformations)

In terms of model making's ability to support lateral transformations, a majority of the student sample registered disagreed (52%) in response. This was in contrast with the sample of practitioners who responded with ratings of neutral (33%) or agreement (41%). This pattern was repeated in responses to model making's ability to support reflection-in-action, with 46% of student responses at disagree and the majority of practitioner responses registered at strongly agree (35%), agree (30%) and neutral (27%):

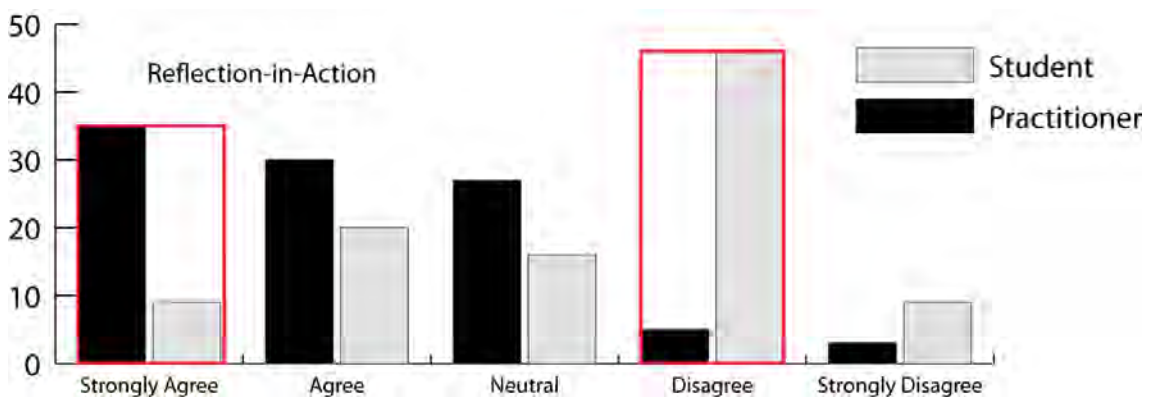


Figure 7.103 Model making is useful for design work that aids reflection and the generation of design ideas (Reflection-in-Action)

With regards to vertical transformations, the practitioner results indicated a tendency towards more positive responses (strongly agree 22%, agree 29% and neutral 38%). A

majority of student responses were distributed between agree (31%) and disagree (35%):

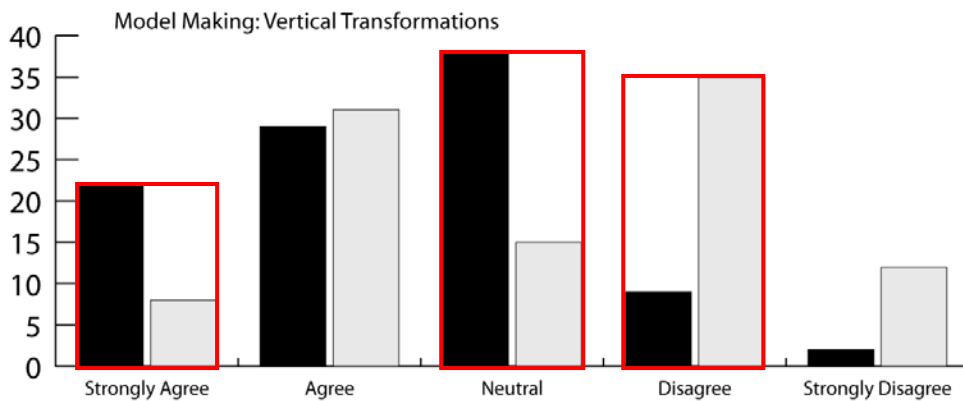


Figure 7.104 Model making is useful for design work on variations of one or the same design idea (Vertical Transformations)

Practitioner attitudes towards both vertical transformations and reflection-in-action were more positive, in contrast to more negative student results. This suggested, as with other tools, that students take a more convergent approach to practice when using model making tools. Evidence of this was identified in their more negative attitudes towards the tool's ability to support lateral transformations and reflection-in-action. With regards to vertical transformations, practitioner findings indicated more positive attitudes. This was in contrast to the students' more mixed response to both vertical and lateral transformations. It may be that a portion of the less experienced designers were more inclined to consider design embodiments, as more fixed in the representation of design intent compared to the practitioners' more open approach.

7.4.7 Rapid Prototyping Tools

Figure 7.105 illustrates practitioner and student responses to the 8 questions relating rapid prototyping tools:

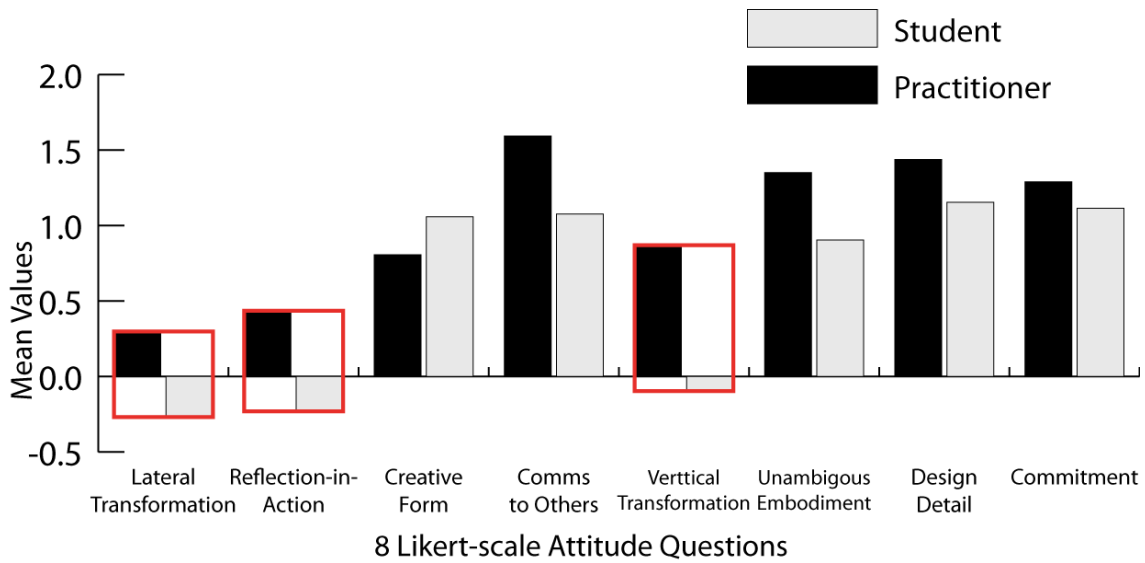


Figure 7.105 Responses to 8 attitude questions on the character of RP

As with model making tools, the greatest difference in response was seen in the tool's ability to support lateral/vertical transformations and reflection-in-action. Figures 7.106 (lateral transformation), 7.107 (reflection-in-action) and 7.108 (vertical transformation) illustrate the distribution of responses across the 3 Likert-scale questions:

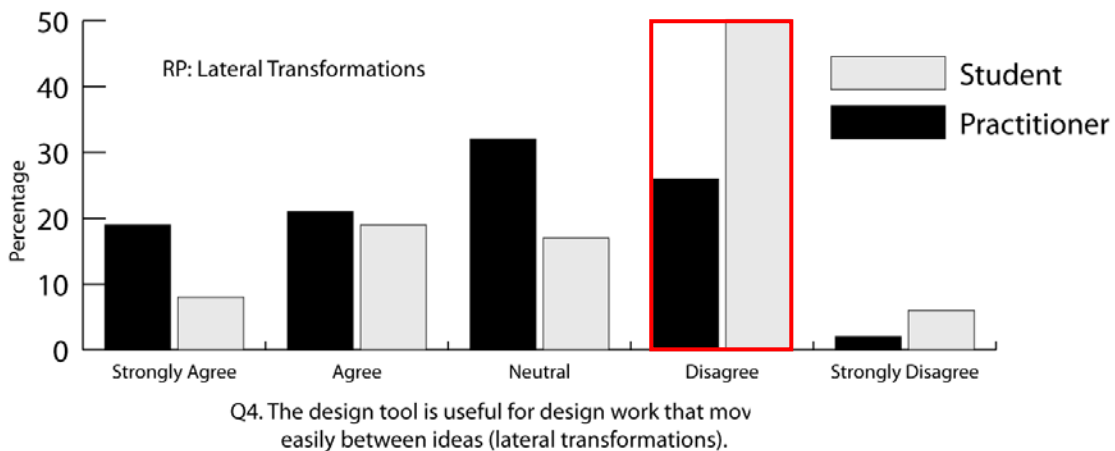


Figure 7.106 Rapid prototyping is most useful for design work that can move easily between design ideas (Lateral Transformations)

Results for rapid prototyping's ability to support lateral transformations drew a mixed response from the sample of practitioners. In contrast, half of the student sample registered a response of disagreement (50%). In terms of rapid prototyping's ability to support reflection-in-action, practitioner responses indicated a tendency towards agreement (strongly agree 26%, agree 28%) with a further 23% registering a neutral

response. In contrast, 50% of student designers responded by registering disagreement.

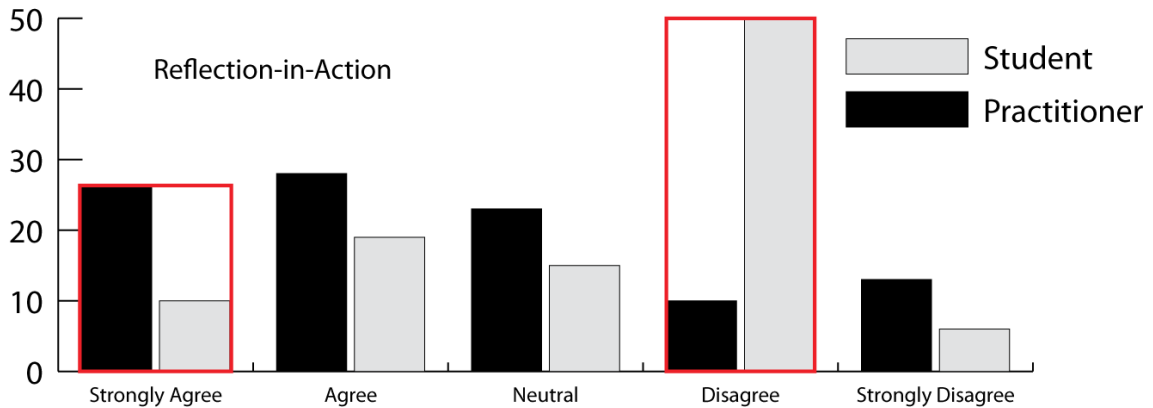


Figure 7.107 Question 8: Rapid Prototyping is most useful for design work that aids reflection and the generation of design ideas: Do you agree or disagree?

In terms of the ability of rapid prototyping to support vertical transformations during design embodiment, practitioner responses were more positive (strongly agree 37%, agree 30%). In contrast student results indicated a more mixed distribution of responses between agree 37% and disagree 31%:

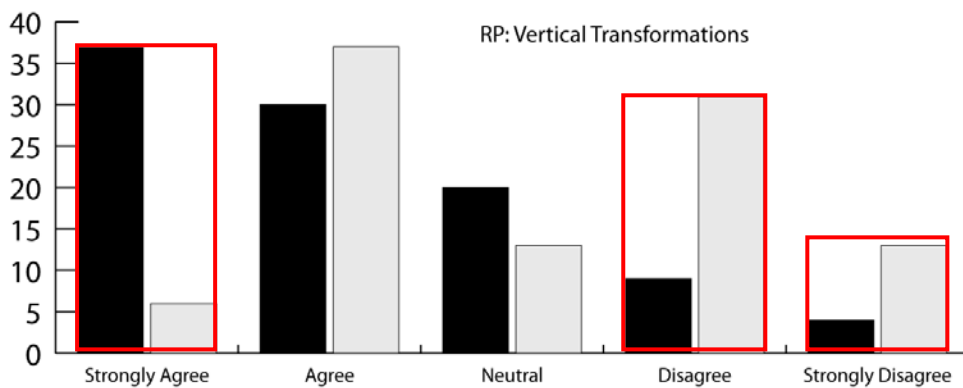


Figure 7.108 Question 5: Rapid Prototyping is most useful for design work on variations of one or the same design idea (Vertical Transformations)

The results indicated different attitudes towards rapid prototyping. Practitioners appear more positive in their attitudes towards rapid prototyping's ability to support those UTCs often associated with divergent design activity (lateral transformations and reflection-in-action). In contrast, a majority of the student sample registered negative responses to the same questions.

Across design tools a pattern emerged relating to the students' more negative responses to those UTCs associated with divergent concept design or any kind of transformation through embodiment of intent.

7.4.7 2D CAD Tools

Figure 7.109 illustrates findings for the two sample groups' responses to 8 questions relating to the use of 2D CAD:

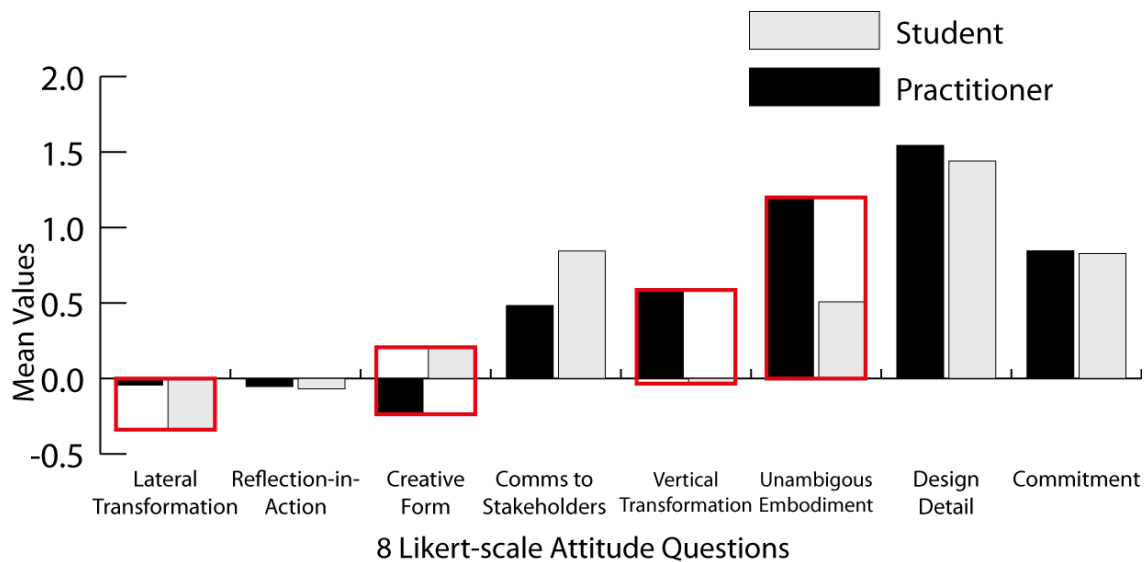


Figure 7.109 Responses to 8 attitude questions on the character of 2D CAD

Unlike many of the other tools (sketch modeling, 3D printing, digital and conventional graphics, 3D CAD, model making, rapid prototyping) there was little difference in responses across the 8 Likert-scale questions. The two exceptions were responses to the tool's ability to support vertical transformations (0.59, -0.03) and the unambiguous embodiment of design ideas (1.20, 0.51). In both cases, practitioners were more positive in their attitudes towards 2D CAD tools.

Emergent in this analysis of the influence of experience upon tool use, are findings suggesting that less experienced designers may consider tools as being less effective in supporting the kinds of embodiments associated with divergent, concept design practice. In this way the section presents results that indicate the influence of the designer over design tool use, and how differences in working methods, influenced by levels of expertise, are reflected in tool engagement. Results also indicated how the use of various design tools (sketch modeling and rapid prototyping for example) may compound existing tendencies towards design convergence. This manifested itself in a more convergent design activity that progresses towards detail design and concept

fixation when uses certain tools (3D CAD, sketch modelling) compared to the practice of more experienced designers.

7.5 The Designer and Design Embodiment

This final section of survey results further considers the role of the designer in influencing the kinds of embodiments made during design activity. Figure 7.110 illustrates this relationship within the model of design activity and tool use:

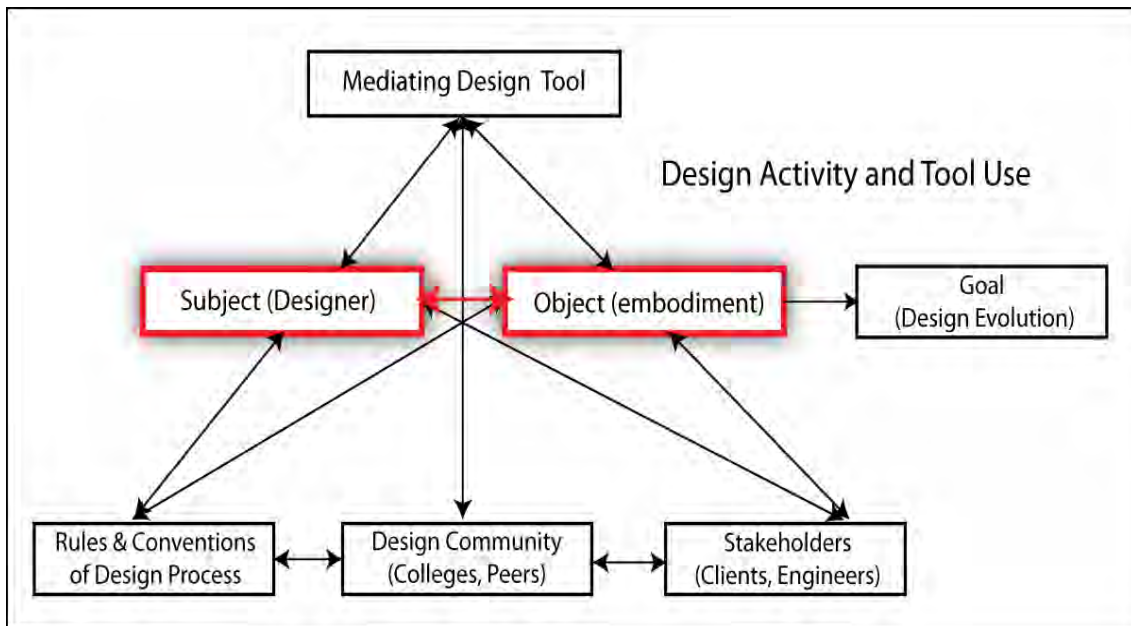


Figure 7.110 Relationship between design practitioner and design embodiment

The analysis of survey data now focuses on UTCs that registered the greatest difference in response between the practitioners and students. Table 17 illustrates the four survey questions that showed the most difference between the two samples and the UTC the four questions were designed to measure:

Survey Question	Difference (Mean Value)	UTC Measured
Question 3.The design tool is useful for representing design ideas unambiguously. Do you agree or disagree?	0.3 to 0.8	Level of Ambiguity Embodiment
Question 4.The design tool is useful for design work which moves easily between design ideas. Do you agree or disagree?	0.1 to 1.5	Transformational Ability (Lateral)

Question 5. The design tool is useful for design work on variations of the same design idea. Do you agree or disagree?	0.1 to 1.0	Transformational Ability (Vertical)
Question 8. The design tool aids reflection and so generation and evolution of ideas. Do you agree or disagree?	0.1 to 1.3	Mode of Communication (Reflection-in-action)

Table 17 Survey questions showing most difference between sample groups

Through this approach the researcher aimed to identify a relationship between design experience and the ways various tools are used to support practice. This relationship between experience and embodiment across the 10 design tools was then employed to consider the designer’s influence upon tool use during design activity.

Results are presented in four sections. Each relating to one of the four questions presented in Table 17. Line graphs are used to plot practitioner and student responses to the questions across the 10 design tools included in the survey. The vertical axis of each graph measures responses to the question as mean scores (see Chapter 6, Coding and Analysis). The horizontal axis presents the 10 tools as they appear in the taxonomy (Chapter 4), from those classified under concept design (left) to those under detail design (right). Student responses are in Grey, practitioners in Black.

7.5.1 Ambiguous Embodiment

This section discusses results for a survey Question asking about the designers’ attitudes towards UTC unambiguous embodiment. Figure 7.111 illustrates practitioner and student responses across 10 design tools:

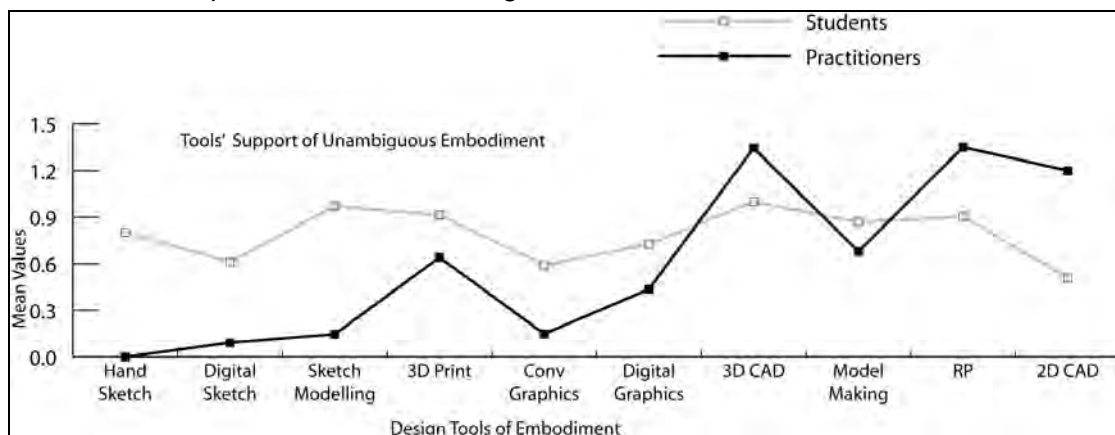


Figure 7.111 The design tools listed are useful for representing design ideas in a more constrained, unambiguous way

Within the sample of practitioners (Black line), Figure 7.111 illustrates an increase in mean responses, from tools often associated with concept design left, to those used during detail design practice, right. There are however spikes (3D printing and 3D CAD). This could indicate a more confident approach to the choice and use of these two tools in terms of their ability to support ambiguity in design embodiment. The results for students are more static across the 10 design tools. These results reflected the mixed distribution of responses to Likert-scale questions relating to the design tools ability to support unambiguity. That is to say, the student sample indicated both agreement and disagreement often in equal measure in terms of the tools' ability to support the unambiguous embodiment of design intent. Practitioner results showed more certainty in responses, with the design tools tending to support or not support unambiguous embodiment. Practitioner results showed responses to unambiguous embodiment increased with tools often associated with development and detail design practice. The exceptions to this were seen in responses to 3D printing and 3D CAD. This may suggest different approaches to the use of tools centred on the notion of ambiguity.

The results indicated that expert practitioners may be more inclined to value unambiguous embodiment during design practice. This may suggest that more experienced practitioners take a different approach to design embodiment and tool use compared to some design students. Results indicated the less experienced designers approach to design activity is informed by a stronger desire to define the design solution, and that this is reflected in attitudes towards ambiguity. On the other hand, and particularly when using tools often associated with divergent and concept design (sketch modeling), the experienced designer is more inclined to exhibit the confidence to use ambiguity and uncertainty in embodiment to explore design intent more widely.

7.5.2 Lateral Transformations

This section explores results relating to survey Question 4. Figures 7.112 illustrates practitioner and student attitudes towards 10 design tools in terms of their ability to support the lateral transformation of design ideas when used during practice:

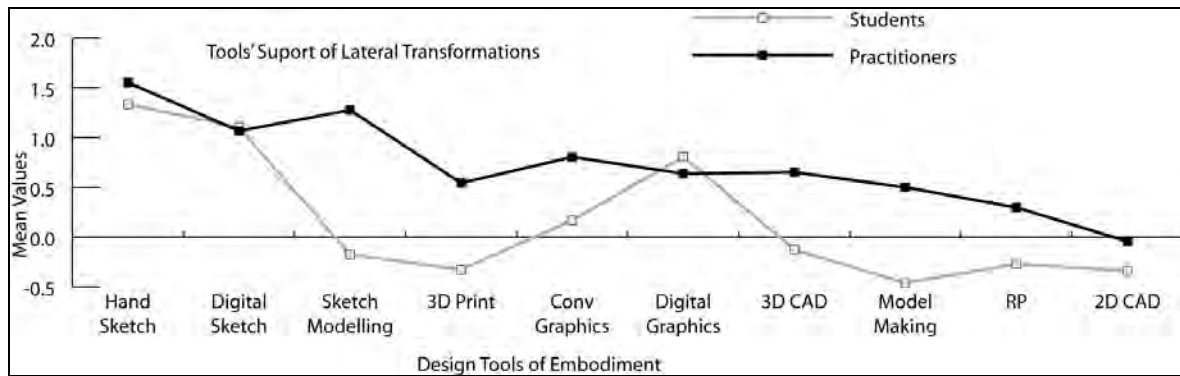


Figure 7.112 The design tools are most useful for design work that can move easily between design ideas (Lateral Transformations)

As with ambiguous embodiment, disparity between practitioner and student responses was seen in the findings relating to the ability of the tools to support lateral transformations. Student mean values were notably more negative in response to sketch modeling, 3D Printing, conventional graphics, 3D CAD, model making and rapid prototyping (Figure 7.112). Also, practitioner findings suggested a reduction in mean responses from a high of hand sketching to a low for 2D CAD. Student responses as a mean score were more erratic across the 10 design tools.

The results indicated different approaches to design embodiment during practice. It could be that students are less inclined to explore the design problem through lateral transformations when compared to more experienced practitioners and that this tendency may be compounded through the use of the design tools sketch modelling, 3D printing and 3D CAD in particular. The students take a more convergent approach to the use of sketch modelling. Experienced designers are more inclined to take a divergent approach to the exploration of the design problem when using design tools. Evidence of this approach was indicated in more positive attitudes towards lateral transformations across the 10 tools.

7.5.3 Vertical Transformations

This section discusses results for the survey question relating to UTC, vertical transformation (Figure 7.113):

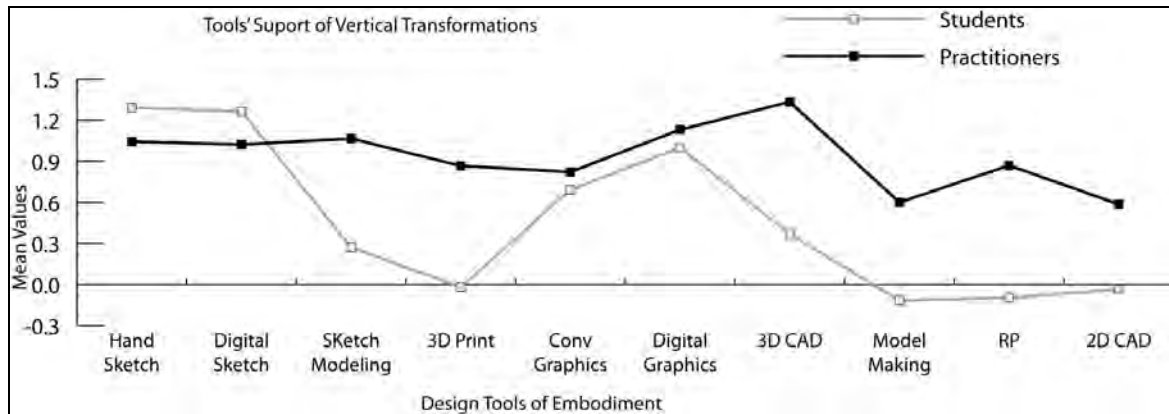


Figure 7.113 The design tools are most useful for design work on variations of one or the same design idea (Vertical Transformations)

Practitioner responses indicated positive attitude towards the ability of all tools to support vertical transformations, with this reducing slightly for those tools often associated with detail design practice (model making, rapid prototyping and 2D CAD, Figures 7.113). In contrast student responses were less positive or mixed in terms of the ability of some tools to support vertical transformation through design embodiment: sketch modeling, 3D printing, 3D CAD, model making, rapid prototyping and 2D CAD. It may be that students consider the use of certain tools as being less effective in supporting any kind of transformation, lateral or vertical, having a tendency to see embodiments made through the use of tools such as sketch modelling, 3D printing and 3D CAD as more fixed. This tendency was indicated in results relating to the ability of some tools to afford either kind of transformation. The practitioners, in contrast, consider all tools to have the potential to support vertical transformations. Evidence of this was indicated in their positive attitudes towards the UTC vertical transformation across the 10 tools.

7.5.4 Reflection-in-Action

This final section presents results relating to the UTC Mode of Communication (reflection-in-action). Figure 7.114 illustrates responses to the ability of the 10 design tools to support reflection-in-action:

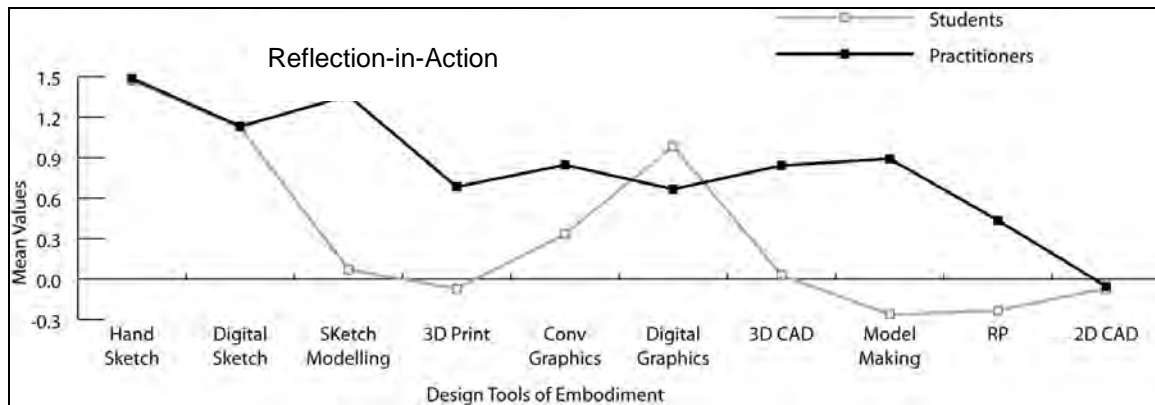


Figure 7.114 The design tools aid reflection and the dynamic generation and evolution of design ideas

Practitioner responses as mean values indicated a decrease across the 10 design tools, from a high of hand sketching to a low of 2D CAD. In contrast, responses from the sample of students differed in terms of sketch modelling, 3D Printing, 3D CAD, model making and rapid prototyping. As with the tools' ability to support lateral transformations, less experienced designers were disinclined to use tools to reflect in action on design intent. This was indicated in their more negative responses. As the UTC is often associated with a more divergent, explorative design activity, the students approach to practice may have a tendency to move design intentions more quickly towards specification and convergence. In contrast, practitioners remain more open to iteration and this difference was indicated in their attitudes towards reflection when using design tools.

7.5.5 Relationships between UTCs

The results indicated a relationship between 2 of the UTCs across the 10 design tools. Figure 7.115 illustrates the relationship between the tools' ability to support reflection-in-action (UTC Mode of Communication) and lateral transformations (UTC Lateral Transformations). The vertical axis measures responses as mean scores. The horizontal axis presents the 10 design tools. The top graph illustrates practitioner results. Student results are presented below:

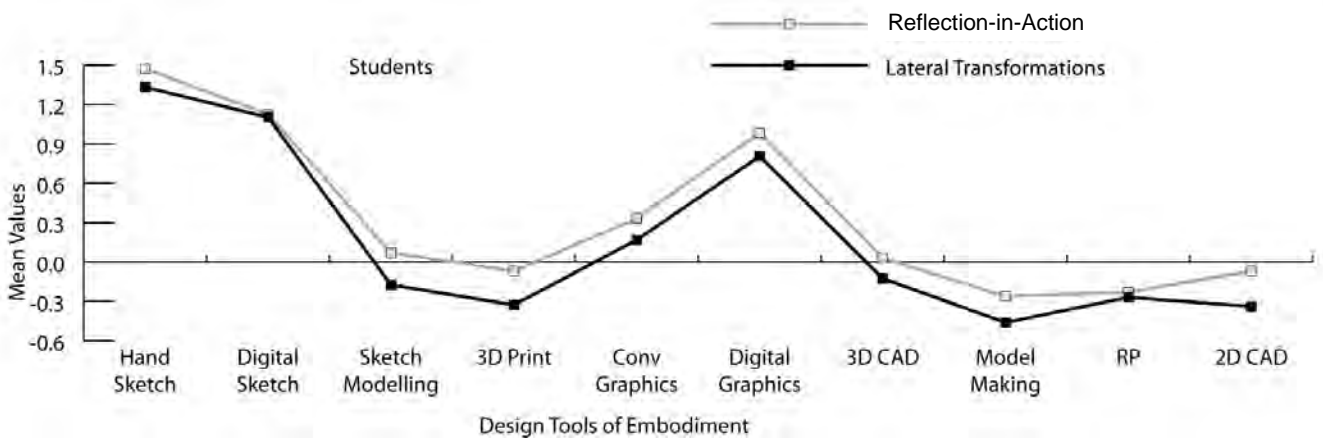
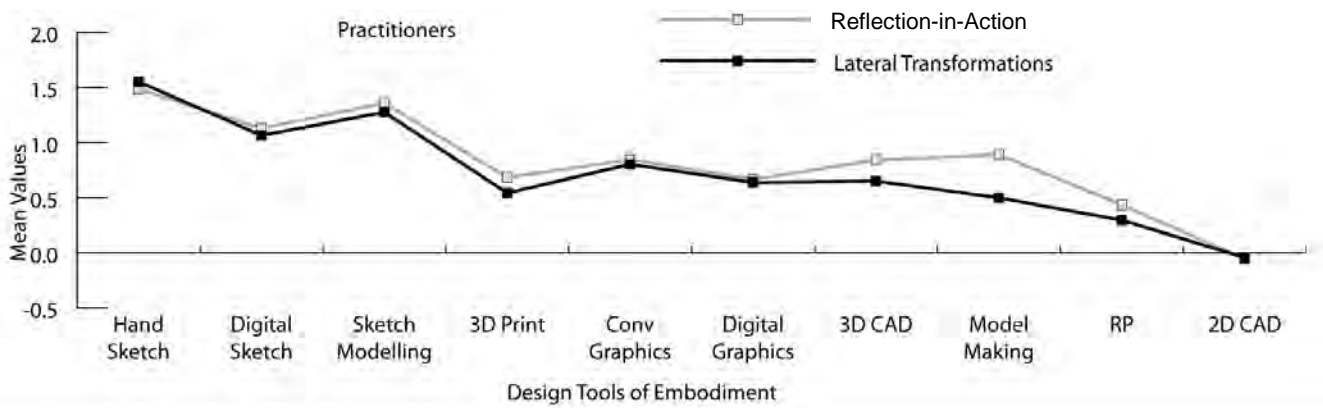


Figure 7.115 Relationship between responses towards reflection-in-action and lateral transformations for practitioners above and students below

Relationships can be seen in both practitioner and student responses to questions relating to the tools' ability to support lateral transformations and reflection-in-action. In the case of the practitioner sample, there is a regression in mean values from a high of those tools placed within the taxonomy under concept design (left), to those used during detail design (right). In terms of the student sample, responses are noticeably less positive towards some tools: sketch modelling, 3D printing, 3D CAD, model making and rapid prototyping. Both the ability to laterally transform embodiment and reflect on those embodiments are UTCs previously associated with divergent, iterative design activity. The results indicated that students might be more inclined to consider some design tools as less effective in support of divergent design practice compared to the sample of practitioners. The survey results start to explore what these differences may be and how they relate to tool use in practice. It appears that design expertise may bring with it an openness towards design practice that is reflected in attitudes towards the use of tools and the kinds of embodiments made. This contrasts with the student's tendency towards design convergence, which is both reflected in and

compounded by their approach to practice and use of design tools: sketch modelling, 3D printing, 3D CAD, model making and rapid prototyping tools.

7.6 Discussion

Results have indicated how design embodiment and tool use is influenced by the practitioner's own working methods and how these methods, in turn, are influenced by design expertise. Results have shown how the designer's experience can influence the appropriation and use of a number of the tools identified in the taxonomy (Chapter 4). Survey results were also considered in terms of relationships between the design tools' implicit characteristics and the kinds of embodiments they may effectively support. In this way, the Model of Design Activity and Tool Use (Chapter 3) was employed as an approach to the analysis of data in terms of relationships between the designer, mediating design tool and the embodiments made through the tool's use.

A first section considered the relationship between the implicit character of the mediating tool and the kinds of embodiments made through its use. Results indicated that the implicit UTCs of various design tools (Chapter 5) inform the types of embodiments that the tool-in-hand is employed to make. Those tools placed within the taxonomy under concept design were rated by the practitioners as strong in their ability to support UTCs often associated with divergent concept design. Those tools used during detail design were considered effective in supporting UTCs associated with more convergent design activity. It is only through the tool that design embodiments are made and, as a result, the implicit character of the tool-in-hand has an influence upon the nature of design activity. This goes some way to explain the use of one tool over another at a given stage in practice. However, results also indicated the influence of the designer's approach to tool use. With experience may come confidence. With this confidence the designer's manipulation of the tool-in-hand alters from erring towards convergence to a design activity that is characterised by its more divergent nature.

However, some design tools, particularly hand and digital sketching and 3D CAD, were rated by the practitioners as effective in design embodiment across a variety of UTCs. Hand sketching was rated as effective in support of those UTCs associated with convergent detail design, as well as those often associated with more divergent, conceptual embodiment; albeit to a lesser degree. Two factors may help explain the reason for this. First, the implicit characteristics of some design tools, such as

sketching and 3D CAD modelling, give them the dynamic flexibility to be employed in a variety of design activities for different purposes: to explore, detail, explain and define. It may also be that design embodiment made through the use of these tools, because of the tools' malleability, is more open to the influence of the designer's own idiosyncratic use of the tool. The designer is better able to manipulate the tool in a way that affords the embodiment of design intent with different characteristics. This then points to the bi-directional nature of tool use in design activity. The tool both influences and is influenced by the design practitioner. What emerges from the survey results is the implication that the relationship between the implicit character of the design tool and the ways in which it may be used to support embodiment of design intent might be more fully understood through investigations that also consider the designer's own influence on tool use. There is a relationship between mediating tool and the kinds of embodiments made, but this relationship is highly sensitive to the practitioner's own influence.

A second section of results compared survey findings from two sample groups: a sample of design practitioners and student designers. In particular, this comparison investigated the relationship between designer experience and attitudes towards the 10 design tools classified within the taxonomy. The results suggested differences in attitudes between sample groups. These differences were identified as a result of the ways in which the student sample responded to questions relating to the characteristics of design embodiments made through the use of the 10 design tools. Student responses differed in two ways. First, the students tended to register confounding responses more often across the Likert-scale items. The students responses were spread widely across the 5 response items within the Likert-scale (strongly agree, agree, neutral, disagree, strongly disagree). In contrast, results indicated a tendency for more certain practitioner responses. Responses tended to agree or disagree with attitude questions rather than be spread across the 5 items on the Likert-scales.

Second, where different responses were registered, the sample of student designers tended to rate tools as less effective in support of those UTCs often associated with divergent concept design (lateral transformations, reflection-in-action). In contrast, a tendency was identified within practitioner results to respond more positively towards the tool's ability to support UTCs associated with divergent design activity.

The findings suggest the relationship between the implicit character of the design tool and their use during studio practice is tempered by the designer's own skills and

expertise. Specifically, the practitioners' attitude towards design tools is a reflection of a more open, iterative approach to tool use and design embodiment during studio practice. The students, on the other hand, may tend towards design convergence and specification sooner with their attitudes towards design tools reflecting this more convergent, fixated approach to studio practice. It may also be that through the use of certain design tools (sketch modeling, 3D printing, 3D CAD, rapid prototyping) these pre-existing tendencies are compounded.

A final section of results further considered the relationship between the practitioner and the kinds of embodiments made during tool use in practice. It presented results across the 10 design tools categorised within the taxonomy. Findings were discussed in terms of the questions identified as registering the greatest amount of difference in responses between the two sample groups. Students seem to take a less positive approach to design embodiment associated with design divergence and exploration through the use of some of the design tools: sketch modeling, 3D printing, 3D CAD, model making and rapid prototyping. The student sample findings indicated a tendency towards unambiguous embodiment through the use of those tools often associated with concept design practice: hand and digital sketching, sketch modeling. The practitioner results, however, indicated that they might take a more ambiguous approach to embodiment through the use of tools associated with concept design. Results indicated that the practitioners' design embodiment through the use of various tools is characterised by a greater tendency towards divergent design activity. This was indicated in practitioner responses relating to those characteristics associated with concept design: transformations, reflection-in-action and ambiguity.

A relationship between attitudes towards 2 UTCs (reflection-in-action, lateral transformations) across the 10 tools were also presented. This indicated a relationship between responses to the 2 UTCs and how this relationship differed between the two sample groups.

The results indicated the designer's use of tools is in part a reflection of their approach to design activity. The implicit character of the design tool will have an influence on the character of design embodiment. However, the tool's implicit characteristics are also manipulated to support various design activities. The nature of this manipulation is dependent upon the skills and expertise of the designer. It seems that, with more experience of practice, the designer's approach to tool use changes in line with a more divergent, less fixated design practice.

Discussion on these co-dependent relationships is generally absent in published literature on the topic of tool effectiveness. Exploring the dynamic qualities of these relationships and how they co-exist to inform tool use and effectiveness, will provide a more holistic understanding and critical engagement with tool use to support development of design pedagogy. For it is the designer who may be best placed to synthesise and benefit from these principles given they are aware of their existence.

Chapter Summary

Survey findings showed designers considered the tool-in-hand to have a significant influence on the kinds of design embodiments made. Results indicated the ways in which the design tool influences the character of design embodiment. For example, the use of hand sketching during design embodiment was seen as effectively supporting lateral transformations (Transformational Ability), ambiguity (Level of Ambiguity), reflection-in-action (Mode of Communication), lower levels of commitment to design intent (Level of Commitment) and the embodiment of form (Level of Detail).

Those tools often associated with divergent concept design (hand sketching, sketch modelling) are valued as tools to support those UTCs often associated with a divergent design activity (ambiguity, lateral transformations, low levels of detail, low levels of commitment, reflection-in-action). Those tools associated with development and detail design (rapid prototyping, 3D CAD) were seen as more effective in support of the embodiment design intent that can be characterised by UTCs often associated with a more convergent design activity (unambiguity, vertical transformations, higher levels of detail and commitment to design intent). This indicated the relationship between the tool and the changing requirements of design activity as it progresses from concept, through development and into detail design. However, results also showed the designers' considered various tools to effectively support a variety of design embodiments. This was particularly true of hand sketching and 3D CAD. For example, although findings indicated hand sketching was most effective in supporting these UTCs associated with divergent concept design (ambiguity, lower levels of detail and commitment), findings also suggested its ability to support UTC associated with convergent specification (vertical transformation, commitment to design intent, detailed embodiment).

Survey results indicated significant differences in practitioner and student attitudes towards design tools. The student designers tended to register more negative responses when asked of the tool's ability to support UTCs associated with divergent concept design (ambiguity, lateral transformations, reflection-in-action). This trend was identified across the 10 tools included in the survey. The practitioners, in contrast, tended to register more positive responses to UTCs associated with divergence. This contrast shows the different approaches the two groups take to design activity and tool use. The student designers' tendency towards convergence, attachment to concept and fixation; the practitioners more open, divergent approach. This suggests the influence of the designer's idiosyncratic approach to practice and how that approach is informed by expertise.

Chapter 8: Results of Interview Study

Introduction

The survey study of industrial design students and practitioners indicated differences in attitudes towards the use of various design tools, reflecting different approaches to design activity (Chapter 7). The survey identified relationships between the implicit character of design tools and design embodiment; the ways in which expertise influences the use of tools and the designer's own influence on embodiment during design activity. The researcher conducted a series of interviews with designers of varying degrees of experience (Chapter 6, Research methods) to explore in greater detail the attitudes of a discreet number of designers. The objective was to provide further understanding of the survey results through their contextualisation through interview findings. This was then used to further address the research aim, objectives and questions presented in Chapter 1 (See Appendix for interview transcripts).

8.1 Presentation of Interview Results

The coding of the interview transcripts using Design Tool Nodes (Chapter 6) revealed a tendency for interviewees to discuss two tools significantly more than any others. Discussion of 3D CAD and hand sketching accounted for approximately two thirds of the total number of references made to design tools across the sample group at interview (see Chapter 6 for complete research methodology).

As a result of this identified bias, further coding and analysis of interview data was restricted to the two Tool Nodes 3D CAD and hand sketching (see Chapter 6). The analysis of conversation between the two Nodes revealed a pattern of discussion that juxtaposed the two tools. That is, designers' tended to compare 3D CAD tools in terms

of hand sketching by suggesting the affordance and limitations of one against the another. The analysis of interview findings then proceeded with the identification of Themes of Discussion within data classified in the two Tool Nodes. 28 Themes of Discussion in 299 references to 3D CAD tools and 42 Themes of discussion in 264 references to hand sketching (Chapter 6, interview coding and analysis).

The Themes of Discussion Nodes were then further coded within 18 Topics of Conversation Nodes (Chapter 6). These Nodes were used as a means to group the 70 Theme of Discussion around common topics. Figures 8.1 and 8.2 illustrate the 8 Topic Nodes relating to 3D CAD and the 10 found in conversation on hand sketching. The distribution of topics within each chart reflects the total number of references made to the Theme of Discussion within each topic (Chapter 6). Considering data in this way provided the approach to exploring the ways interviewees discussed the two design tools (Bryman 2008).

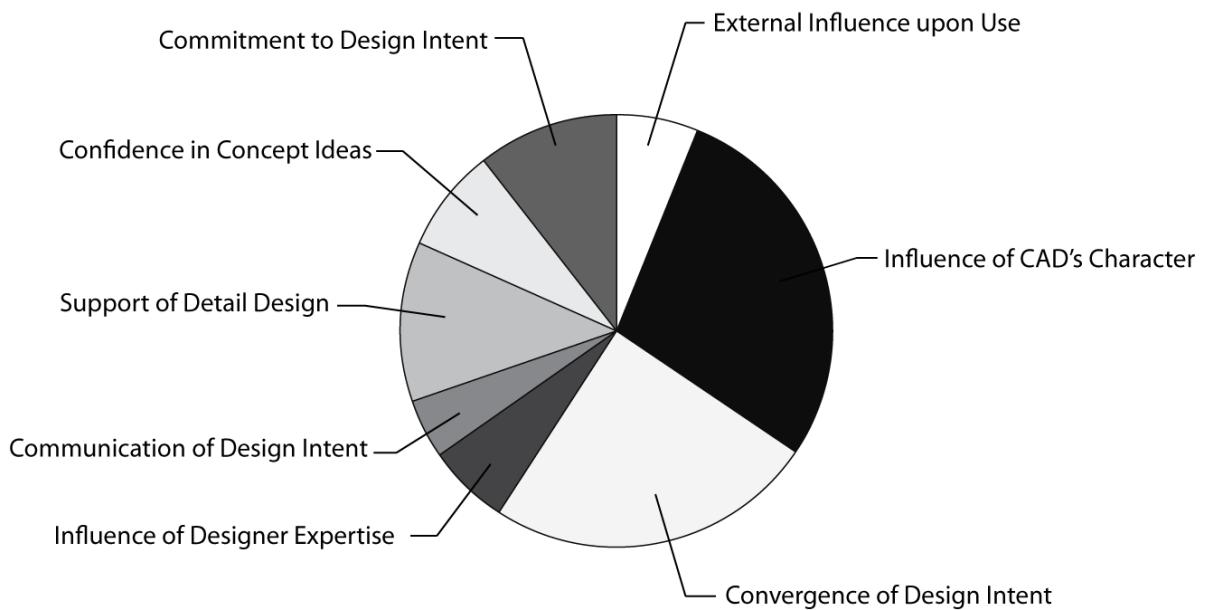


Figure 8.1 8 Topic of Conversation Nodes across 3D CAD

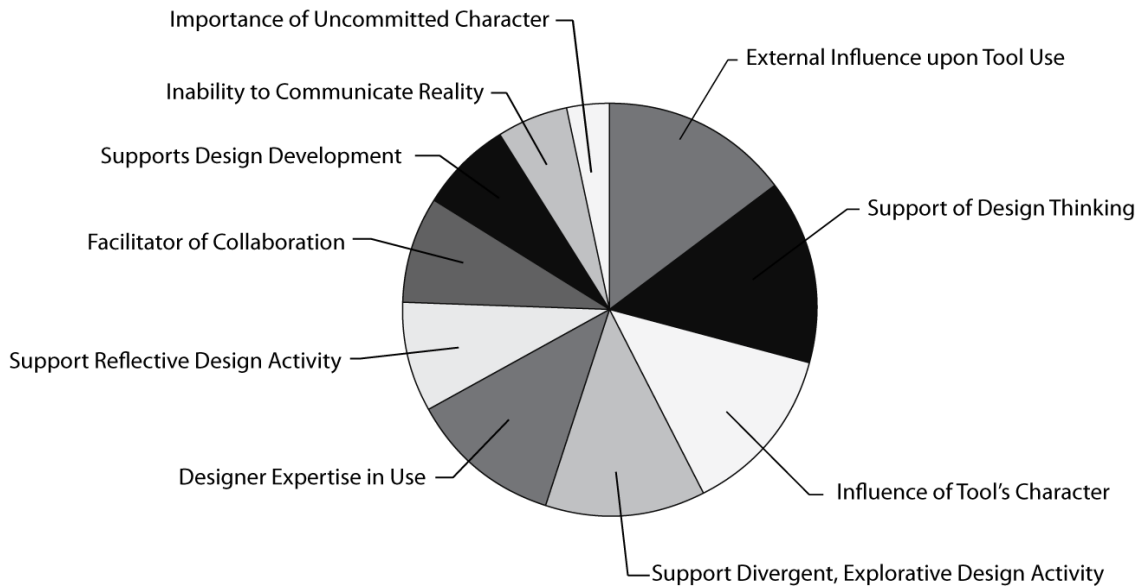


Figure 8.2 10 Topics of Conversation Nodes across hand sketching

Of the 18 Topic of Conversation Nodes (8 3D CAD and 10 hand sketching) three were identified in both the conversations on 3D CAD and hand sketching (Table 18). A further eight suggested contrasting attitudes between the two tools (Table 18). The remaining one topic identified within discussions on 3D CAD suggested commonality with one other hand sketching topic. Two further topics were identified in discussion of hand sketching only (Table 18):

Topic of Conversation Nodes	Found in Discussion of design Tool	
	Hand Sketching	3D CAD
External influence upon tool use	Hand Sketching	3D CAD
Influence of tool's character	Hand Sketching	3D CAD
Designer expertise in use	Hand Sketching	3D CAD
Convergence of design intentions		3D CAD
Support of divergent, explorative design activity	Hand Sketching	
Support of detail design		3D CAD
Support of design development	Hand Sketching	
Inability to communicate reality	Hand Sketching	
Use for Confidence in concept Ideas		3D CAD
Importance of uncommitted character	Hand Sketching	
Commitment to design Intent		3D CAD

Facilitator of collaboration	Hand Sketching	
Support of design thinking	Hand Sketching	
Communication of design intent		3D CAD
Support of reflective design activity	Hand Sketching	

Table 18 Topics of Conversation, 3D CAD and hand sketching

In the presentation of interview results, Topics of Conversation and the Themes of Discussion classified within each topic are considered in terms of how they relate to the Model of Design Activity and Tool Use (Chapter 3). The aim of this approach was to further investigate the emergent findings from within the survey study (Chapter 7):

- Designer attitudes towards the implicit character of design tools and how these attitudes inform design practice.
- The relationship between design expertise and the use of tools.
- The influence of the designer’s approach to activity and how this influences the types of embodiments made during practice.

The presentation of interview results proceeds in the following sections with reference to the Topics of Conversation presented in Table 18. Within each section, a single Topic of Conversation on hand sketching is compared to one relating to 3D CAD. The schedule of this presentation is shown in Table 19:

Section	Topics of Conversation
8.1.1	External Influence upon Tool Use (sketch & CAD)
8.1.2	Influence of Tool’s Character (sketch & CAD)
8.1.3	Designer expertise in use (sketch & CAD)
8.1.4	Convergence of design intentions (CAD) Support of divergent and explorative design activity (sketch)
8.1.5	Support of detail design (CAD) Support of design development (sketch)
8.1.6	Use for Confidence in concept Ideas (CAD) Inability to communicate reality (Sketch)
8.1.7	Commitment to design Intent (CAD) Importance of uncommitted character (sketch)

8.1.8	Communication of design intent (CAD) Facilitator of collaboration (sketch)
8.1.9	Support of design thinking (sketch) Support of reflective design activity (sketch)

Table 19 Presentation of interview results

Pie charts illustrate the number of references made to each theme classified within the Topic of Conversation Nodes (Chapter 6). In front of each chart a table is presented. The table shows the Themes of Discussion coded under each Topic of Conversation (left column) and the number of references to each theme (right column). The segmentation shown within each Pie chart illustrates the total number of references to the Themes of Discussion classified under the Topic of Conversation Nodes.

In this way a comparison was made between Topics of Conversation relating to discussion of 3D CAD and those for hand sketching tools. Results are supported through direct quotation from the interviewees.

8.1.1 External influence upon Tool use (Sketching & 3D CAD)

Figure 8.3 illustrates how the Topic of Conversation ‘external influence upon use’ (found in the discussion of both tools) related to the Model of Design Activity and Tool Use presented in Chapter 3.

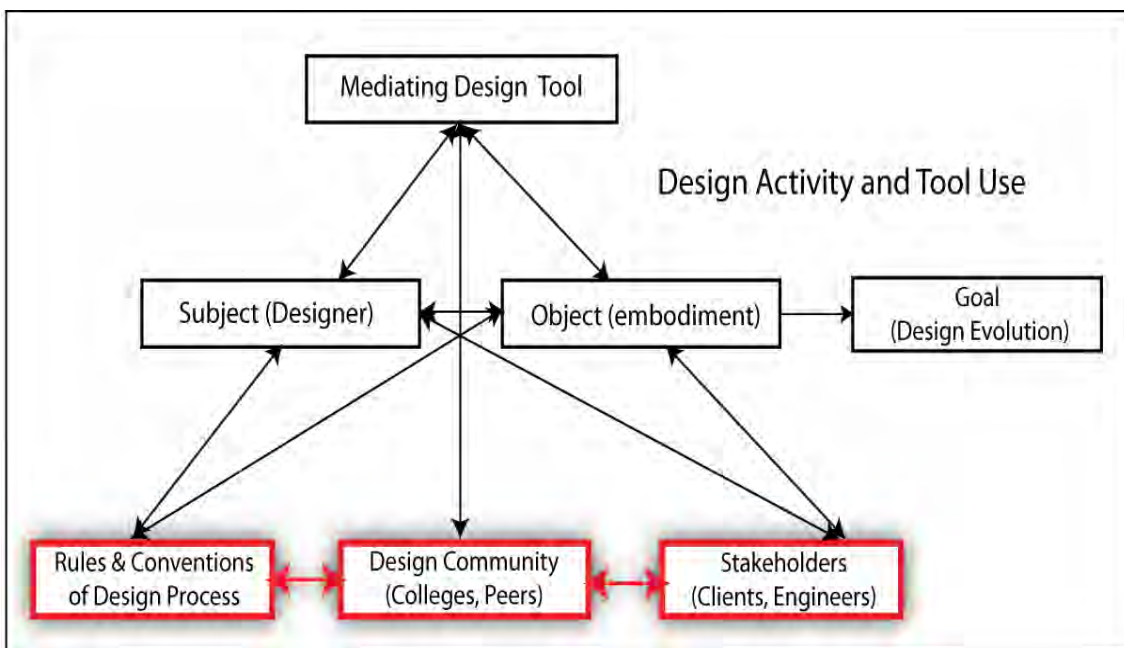


Figure 8.3 Role of External Influence upon Tool Use within model of design activity

The Topic of Conversation appeared to relate to the context within which the designer will use tools in support of design activity (Figure 8.3): the ways in which the requirements of the design process will influence the use of tools (Rules & Conventions); the influence of other designers and peers (Design Community); and that of other clients (Stakeholders). Figure 8.4 illustrates results for the Topic of Conversation's External Influence on Tool Use:

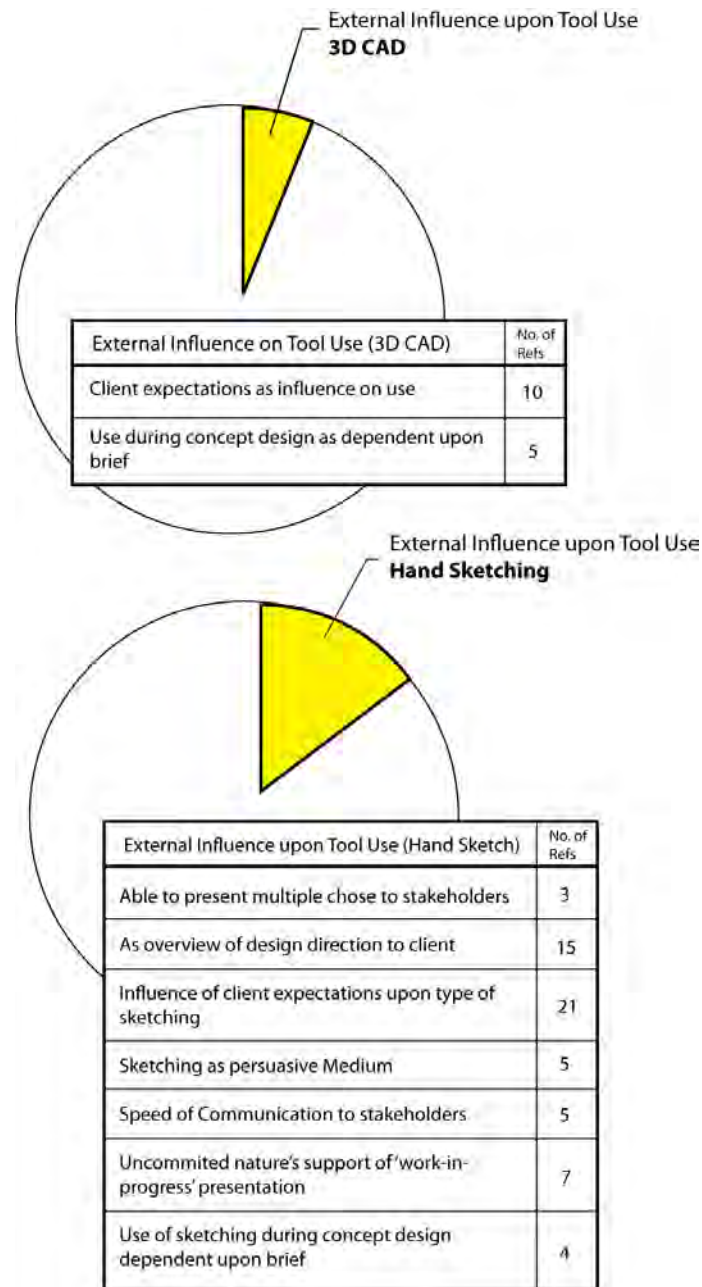


Figure 8.4 Topic of Conversation: External Influence Upon Tool Use. Only two Themes of Discussion cited for 3D CAD, seven for hand sketching

The results indicated that designers made a greater number of references to external influences when discussing hand sketching compared to 3D CAD (Figure 8.4). In conversation on both design tools, client expectations were cited as influencing tool use (3D CAD two Themes, 10 references, hand sketching seven themes, 21 references). When speaking of stakeholder influence, interviewee Pr.05 described a balance between the use of hand sketching and 3D CAD tools in the presentation of design proposals. Sketch embodiment was seen as representing design intent in a less finished way which the client may then not be able to fully interpret. Pr.05 also indicates a relationship between the client's previous experience of design embodiment through 3D CAD tools and how this influences the tool's use:

We've been bitten before by showing things too raw in sketch stage, where the client just doesn't get it. If the client is familiar with seeing the 3D CAD, they want that right at the early stage of the process.

(Interviewee.Pr.05)

Designer Pr03 indicated the relationship between the use of design tools, and the need to satisfy stakeholder expectations, suggesting the importance of creating a feel for the progression of design ideas. In contrast with Pr.05, Pr.03 suggested that 3D CAD tools were not used during the presentation of concepts due to concerns over the ways they may provide an impression of design evolution that was too advanced:

At the first stage we never show 3D [CAD] because that has gone too far in giving the wrong impression.

(Interviewee.Pr.03)

The designers appeared to emphasise the importance of an awareness of stakeholder expectation when using tools in the embodiment of design intent. Interviewee Pr.02 spoke of client needs and an the importance of ability to align design embodiment with client expectations:

Need to pull these together to present to clients, or show the clients the ideas in a way they can understand, present a number of choices, like I said five or six clearly. If you where to just show a sketch book of ideas or part of a sketch book, clients probably might find it difficult to get a clear understanding.

(Interviewee.Pr02)

The discussion indicated the relationship between stakeholder expectations and the use of design tools in the embodiment of intent. The results suggested that the designers were particularly concerned to emphasise the importance of understanding how stakeholder expectations necessarily influence the kinds of embodiments made during activity. It appears that clients and other stakeholders have a significant influence on design activity and tool use.

Findings also indicated the role of the designer's own studio environment and working culture on attitudes towards tool use (design community, Figure 8.3). Designer Pr.02 tended to use 3D CAD during concept presentation while designer Pr.05 was more skeptical of the tool's ability to support conceptual design activity. All designers, however, showed a concern for the different ways that the two tools could communicate with clients and other stakeholders. Pr.05 spoke of a balance between 'committed' and 'less committed' embodiment and an awareness of client expectations (see UTC: Level of Commitment, Chapter 5):

I suppose that's where we've learnt from either showing too raw a presentation or going in too finished. If you go in too finished it can be detrimental as well. And there's never a happy medium, it's always a balance.

(Interviewee.Pr.05)

The designer's discussion of tool use suggested that, in both 3D CAD and hand sketching, client expectations influenced design activity. With regards to CAD and, to a lesser extent sketching, the designers also cited the project brief as influential in the choice and use of design tools. In terms of hand sketching, interviewees tended to discuss a number of external influences. These included sketching's ability as a persuasive medium; speed of communication; the uncommitted nature of embodiment through sketch tools; and the sketches ability to support an overview of design direction.

For hand sketching, and to a lesser extent 3D CAD, the results suggested the use of tools as being influenced by what the designers considered were the types of embodiments required in order to communicate at the right level at a given stage in

practice. It may be that the relationship between tool use and client expectations is stronger in the use of hand sketching compared to 3D CAD tools, as suggested in the greater number and variety of references to the influence of the design process.

This understanding of relationships between stakeholder wishes and tool use was considered by PR.02 to be important in the communication of design intent:

If the client is familiar with seeing the 3D CAD, they want that right at the early start of the process. The flip side of that is if you show them CAD too early they think that's it there's no development to do. They think the jobs done. What are we doing over the next two stages?

(Interviewee Pr.02)

Designer Pr.02 described his awareness of client expectations and a concern for the effect of embodiment as influenced by the character of the design tool. The results indicated that in order to successfully balance the use of tools and client expectations, the designer considered the kinds of tools used against the ways in which they may communicate design intentionality, thereby creating the optimal conditions to support communication of design intentions to stakeholders.

Discussion classified under the Topic of Conversation 'external influence upon tool use' indicated the significance of the context within which tool use takes place. This was expressed in the model as 'design community', 'rules & conventions of studio practice' and 'stakeholders'. Designers cited a greater number and variety of influences relating to hand sketching compared to 3D CAD (Figure 8.4), tending to speak of sketching as being influenced by a wider variety of external factors. It may indicate perceptions of the kinds of activity undertaken during a stage in the design process and, most importantly, how the expectations of stakeholders relate to this, which then influences the ways tools are used. Future investigation of tool use will benefit from a consideration of these wider external contexts, thereby providing a more holistic understanding of tool use during design activity.

8.1.2 Influence of Tool's Character

Figure 8.5 illustrates how, 'Influence of Tool's Character' related to the Model of Design Activity and Tool Use (Chapter 3):

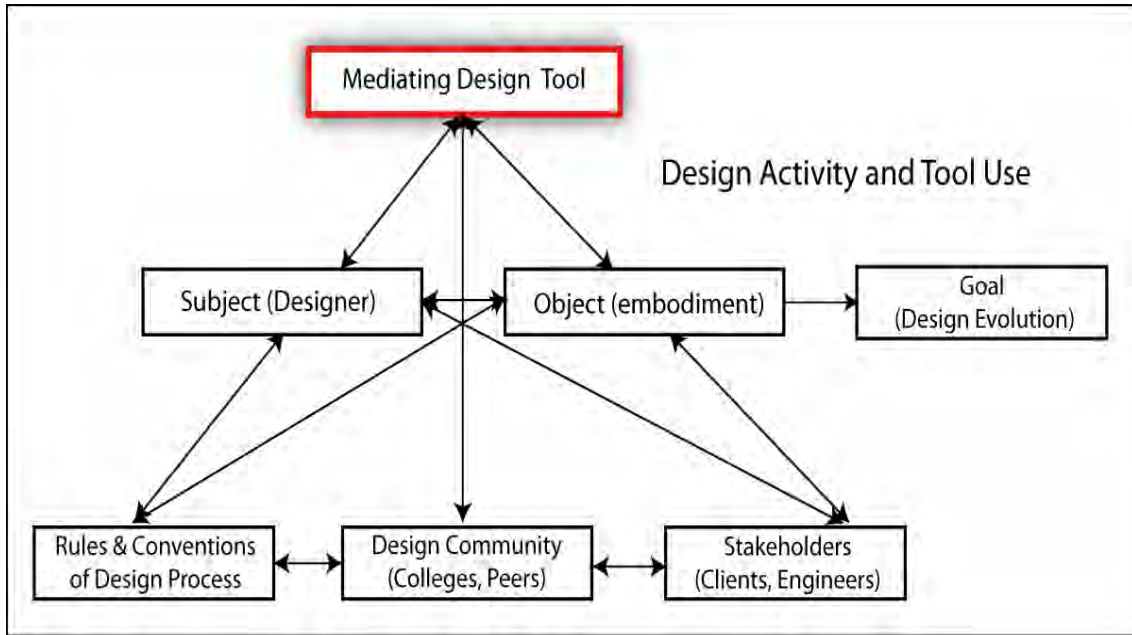


Figure 8.5 Role of Influence of Tool's Character within model of design activity

Figure 8.6 illustrates results for the Topic of Conversation Influence of Tool's Character for both 3D CAD and hand sketching, together with the Themes of Discussion coded under each topic:

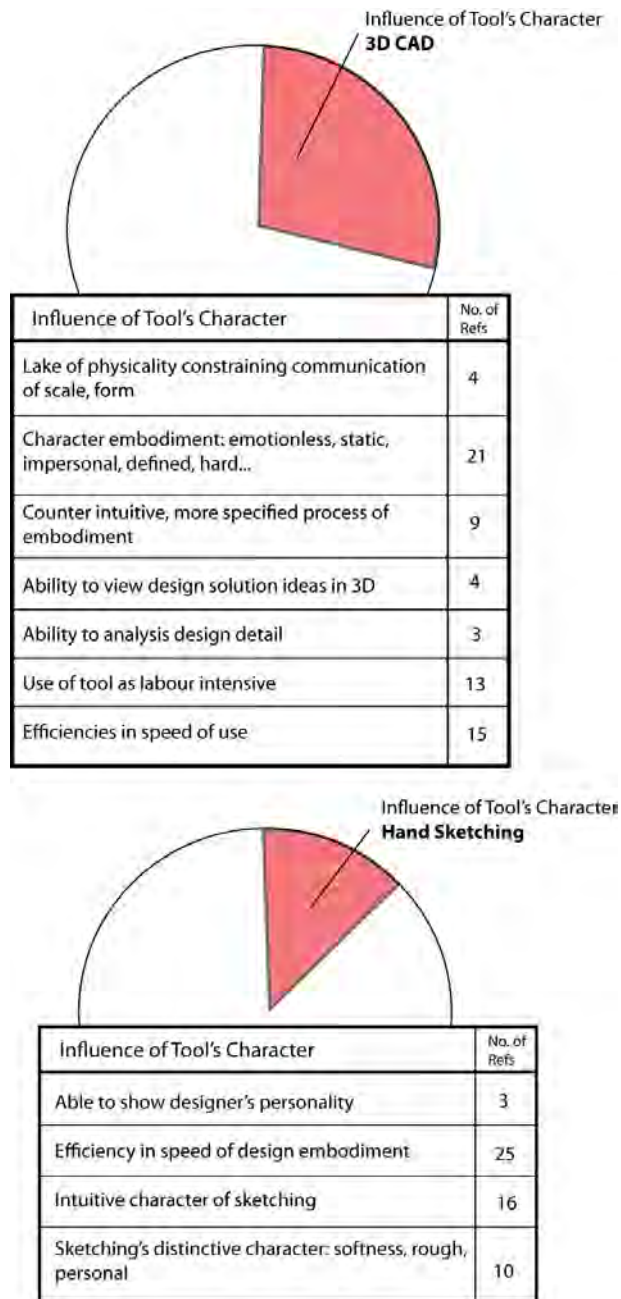


Figure 8.6 Topic of Conversation: Influence of Tool's Character. Seven Themes of Discussion cited for 3D CAD, four cited for hand sketching

Classification of references to the influence of the tool's character indicated that designers made reference to the implicit character of 3D CAD more often than hand sketching (Figure 8.6). In both 3D CAD and sketching, Themes of Discussion were identified relating to speed of embodiment (3D CAD 15 references, hand sketching 25 references). The intuitive character of sketching received 16 references and the counter intuitive nature of 3D CAD received 9. Designers spoke of the specific and

defined character of 3D CAD (21 references) compared with the more personal, undefined nature of hand sketching (10 references).

Pr.05 spoke of the character of design embodiment through hand sketching as related to the idiosyncratic personality of the design practitioner, suggesting this influence on design embodiment was lacking in the use of 3D CAD tools:

You could see a lot about the person that created that (referring to image of a hand sketch). That's all gone in CAD. And that's what's missing. Which you know, the tablet side of thing (graphic tablet used as digital sketch tool) comes back in. Personality can come across.

(Interviewee Pr.05)

Conversation on the character of 3D CAD tools tended towards the discussion of limitations and constraints. This contrasted with the designers' discussions of hand sketching which tended towards its affordances. Pr.04 showed a concern for the ability of CAD tools to support a particular kind of thinking about the design problem and consideration of solution ideas. The designer suggested that the use of CAD tools could be limiting in that the embodiments they made became the goal of the activity, rather than being a conduit through which design ideas are progressed:

Then if you see some sketches or some variations, then you can begin to assess whether that person has actually made some informed choices or whether they just went into their CAD package and drawn the most sexy looking thing they could.

(Interviewee Pr.04)

Designer Pr.01 discussed CAD in terms of a lack of 'personality' in the way that the tool embodies design intent.

And then the emotion side of things, I think it is because it's so clean, so perfect (3D CAD)...When you have a static 3D object that you spin round on a screen it does feel static.

(Interviewee Pr.01)

Related to this, interviewee St.02 compared 3D CAD with sketching in the ability of the latter to embody the designer's own personality.

But again it [sketching] has that softness that CAD kind of doesn't. CAD is kind of very harsh and, you know, finished. Whereas the sketching is like, well I don't really like that (image of 3D CAD model), you know?

(St.02)

CAD's ability to analyse design detail and its flexibility in viewing the design embodiment from various angles was also discussed. However, a lack of physicality and a counter intuitive interface were cited as constraining characteristics (Figure 8.6). This was in contrast to discussion of hand sketching that focused upon its ability to support exploration through the impressionistic or undefined character of design embodiment (Figure 8.6).

Conversation relating to the influence of the tools' character suggested that the designers' considered the character of 3D CAD to have a strong influence on the embodiment of design intent during the design practice of less experienced designers:

The student's problem is that they don't know how to model what they've designed on the computer. So their designs are actually influenced by that they can achieve on the computer.

(Interviewee Pr.01)

Interview results suggested that designers' considered the character of the mediating design tool as important in the kinds of embodiments made during practice. However, the results also indicated a contrast in how the two tools' characteristics were seen as influencing design activity. Interviewees tended to describe hand sketching as effective in more divergent, iterative activity; 3D CAD was more useful during convergent design.

As with the survey results (Chapter 7) findings indicate that attitudes towards the implicit character of a given tool has an influence upon the kinds of design activity that a tool might be used to support. How much these perceptions are a reaction to the implicit character of a given tool and/or the designer's own idiosyncratic working methods are important questions in understanding the use of design tools.

The Interview findings suggest that although the sample tended to view 3D CAD as a convergent tool, when compared to sketching's use during explorative design, departures from this position were seen in conversation of the two tools. Due to the seemingly rich and complex nature of design activity, the use of CAD and/or sketching at a given stage in the design process is not only defined by the tool's character, but is a result various other influences. The interview findings suggest that these include the critical influence of designer's idiosyncratic use of tools together with the context of the tool's use.

8.1.3 Designer Expertise in Tool use

Figure 8.7 illustrates how the Topic of Conversation, 'Designer Expertise in Tool Use' related to the model of design activity:

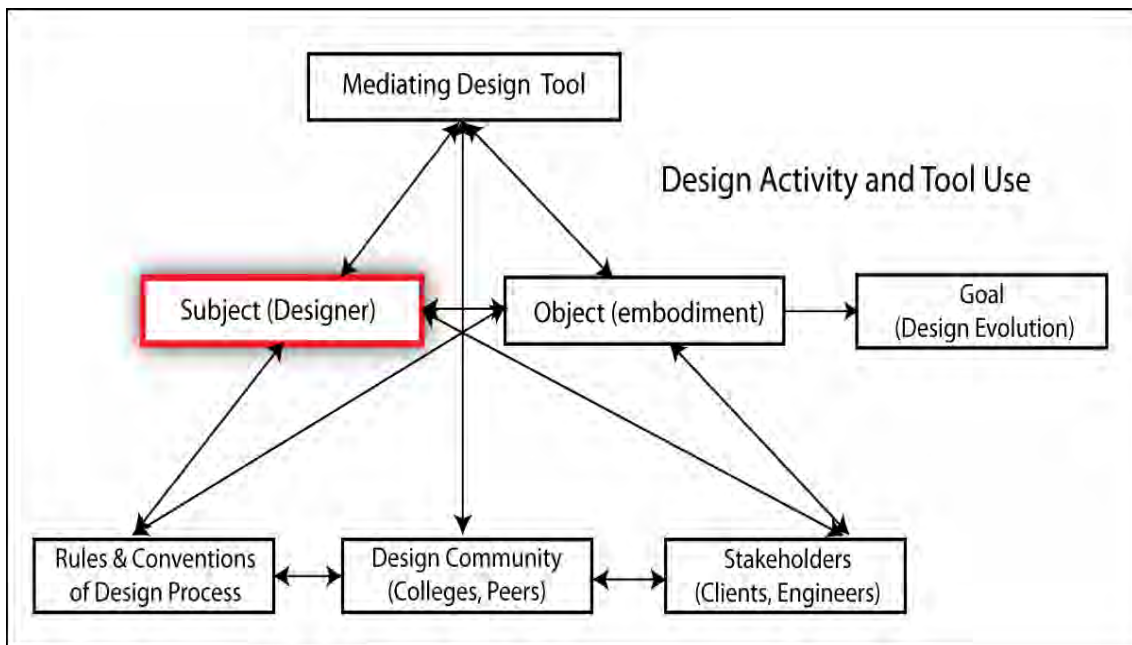


Figure 8.7 Role of Designer Expertise in Tool Use within model of design activity

The topic identified instances of discussion relating to the designer's own skills and experience: the influence of expertise on the ways in which the design tool is used in support of design activity at various stages in the design process (Figure 8.7). The topic identified with survey results (Chapter 7), suggesting the influence of expertise on the designer's approach to design activity and tool use.

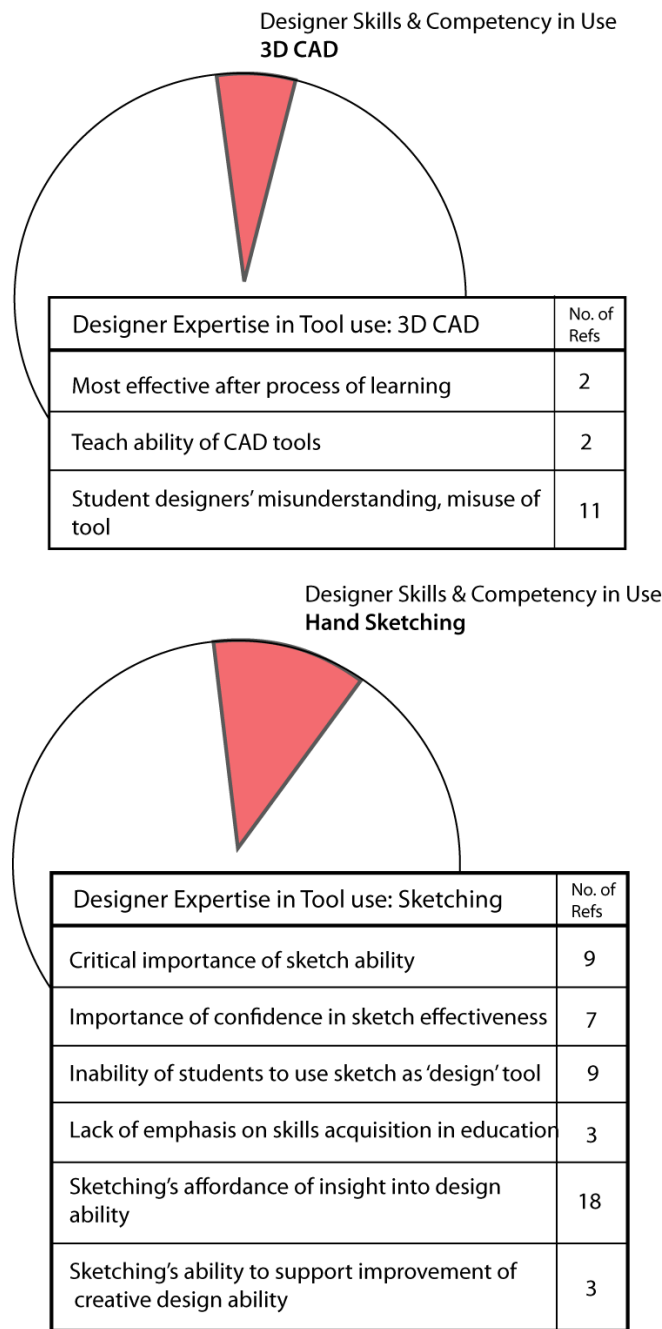


Figure 8.8 Topic of Conversation: Designer expertise in Tool Use. Three Themes of Discussion cited for 3D CAD, six for hand sketching

In discussions of both 3D CAD and hand sketching, designers spoke of expertise in relation to tool effectiveness and cited inexperience as negatively impacting this effectiveness. Interviewee Pr.01 talked of the ability to gauge the designer's thought process when viewing design sketches:

I think so because you can see their thought process (when sketching). If, that's what I also like, original sketches... I'd like to see the twenty sheets

and see that, actually, there's a bit of rough sketching there, but it'll give an idea to their thoughts.

(Interviewee Pr.01)

This indicated a relationship between design activity and the influence of 3D CAD tools where the tool may be constraining because the limited experience of practice increases the tool's influence upon activity. The designers were concerned that this resulted in the influence of the tool becoming too dominant.

Designers Pr.01, Pr.04 and Pr.05 suggested that a lack of confidence related to experience as influencing the ways in which sketching is used to support design activity. This resulted in what they perceived as an over-reliance on 3D CAD tools:

People aren't confident with their sketching and they won't do it

(Interviewee Pr.05)

Designer Pr.04 and Pr.05 suggested that students lacked an understanding of the purpose of design sketching as an aid to the communication of design ideas. Interviewee Pr.04 suggested that instead of supporting design activity, less experienced designers tended to consider the sketch as an outcome in and of itself.

Somebody will put sketches in, rather than to explain their design thinking sort of like this is what I did on the weekend kind of sketch... almost like they're drawing a picture rather than using a sketch to communicate or explain an idea... Then if you see some sketches or some variations, then you can begin to assess whether that person has actually made some informed choices.

(Interviewee Pr.04)

Designer Pr.03 spoke of what he saw as the student's desire to use CAD tools at the expense of sketching:

There's a student, 'oh, I love 3D. I can do it easily. I don't worry about sketch', I [emphasis on 'I'] worry about it.

(Interviewee Pr.03)

Interviewees expressed concern for the less experienced designer's use of 3D CAD which centred on a perception of CAD's influence upon the kinds of design embodiment afforded through its use. Designers with limited experience may therefore be less aware of this influence. Pr.05 spoke of this effect on the student design activity:

If they (students) started building something in CAD they will almost force it to work because of the labour that's gone in up to that point.

(Interviewee Pr.05)

This perception of student inability was also seen in discussion of hand sketching. As previously suggested, there was concern for the kinds of sketch embodiments made by student designers and the relevance these had to design practice. The designers' discussed the importance of understanding the affordance and constraints of hand sketching in its support of the design process to explore, develop, iterate and/or specify design ideas. This understanding seemed tied, designers suggested, to a designer's ability to see the tool as part of a wider context of practice rather than to allow the tool become too dominant in support of design activity.

Findings from the interview study suggested that designers saw both the competent use of sketching and 3D CAD tools as being important to the tool's effectiveness. In both cases, interviewees identified less experienced designers (students) as having a limited ability to fully understand the influence of design tools as they are used to support design practice. In the case of 3D CAD, this lack of understanding manifested itself in the increasing influence of CAD's implicit character. In terms of sketching, interviewees cited a lack of confidence with its root in an inability to understanding the relationship between the tool's use and its role in support of a process of design. Some interviewees indicated that design embodiment, through hand sketching, offered insight into design ability, often explicitly citing the effective use of the tool as an indicator to judge levels of expertise in design thinking and creativity.

The interview results together with survey findings have indicated the nature of the relationship between the design practitioner and tool use during design activity. Designers appear to consider expertise as playing a practical role in understanding the relationship between design tool, activity and the wider context of practice. This understanding relates to the practitioner's awareness of the fundamentals of design activity; communication; exploration; the embodiment of the what-might-be in ways that may support convergent; and/or divergent exploration of design problems. The

interview findings indicated a lack of student engagement with these fundamentals that resulted in tools being used less effectively in support of design activity. Survey findings indicated the students' more convergent approach to tool use. Findings indicate a lack of confidence and convergence in the practice of inexperienced designers.

8.1.4 Convergence of Design Intentions & Support of Divergent Activity

Figure 8.9 illustrates how the topic of conversations 'Convergence of Design Intentions' (3D CAD) and 'Support of Divergent Activity' (hand sketching) related to the model of design activity and tool use:

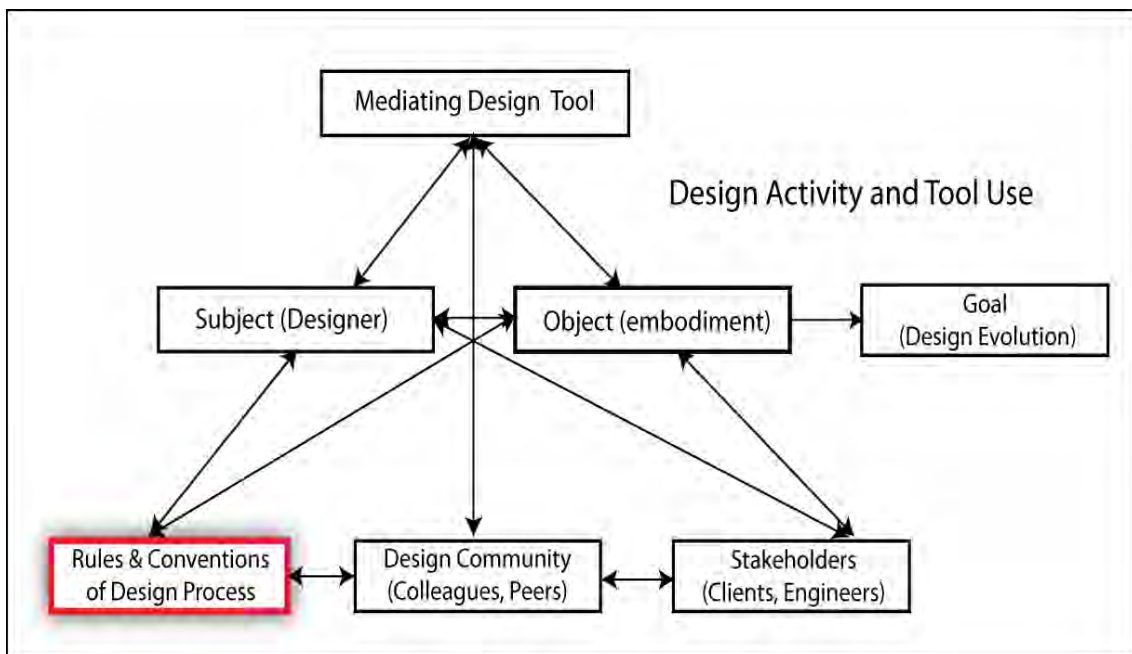


Figure 8.9 Role of Convergence of Design intentions and Support of Divergent Activity within model of activity

A requirement to explore design ideas (divergent design activity) and to converge design intentions towards final specification for manufacture (convergent of design intentions), are both characteristics of the design process. The Topics of Conversation identified discussion of tool use in relation to the influence of divergent/convergent design (Figure 8.10):

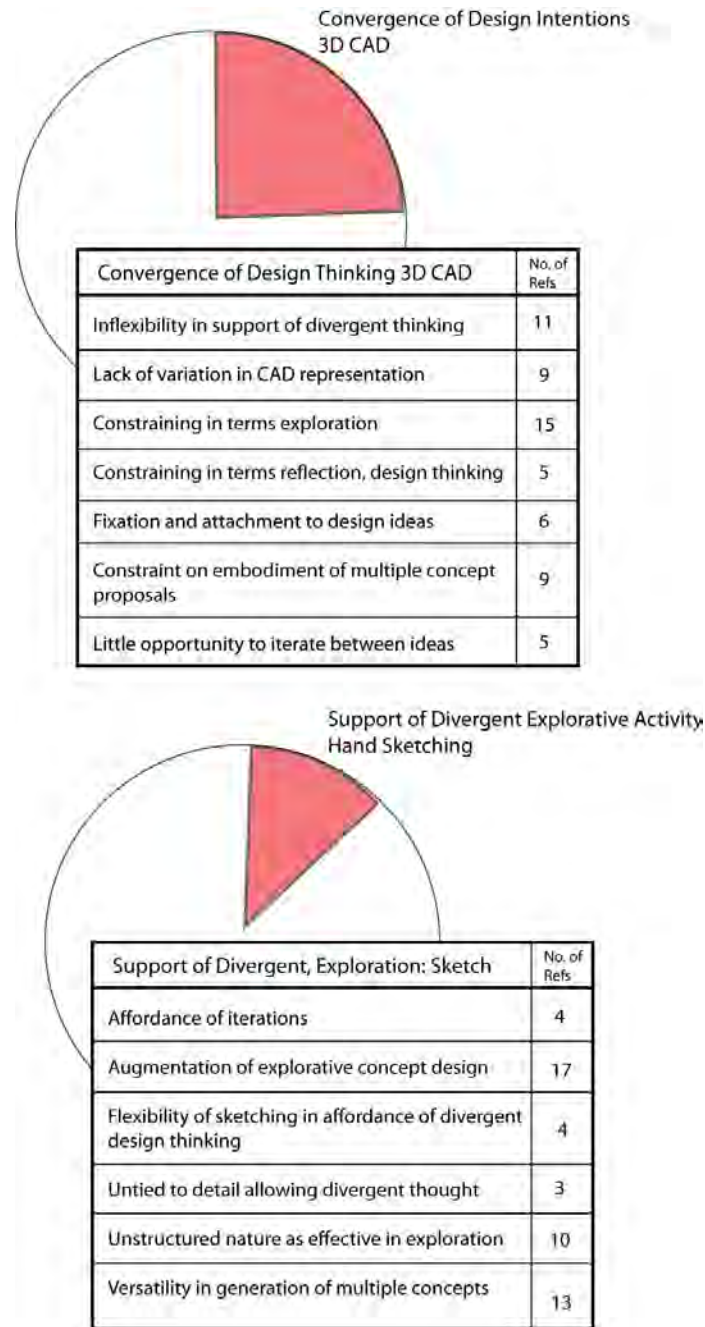


Figure 8.10 Topics of Conversation: Convergence of Design Intent & Support of Divergent Activity. Seven Themes of Discussion cited for 3D CAD, six for hand sketching

Discussion on the tool's ability to support convergent/divergent design was identified in conversation relating to hand sketching and 3D CAD. In terms of 3D CAD the Themes of Discussion: inflexibility in support of divergent thinking (11 references) and constraint in terms of exploration (15 references) were identified. In contrast, discussion relating to hand sketching tended to centre on characteristics associated with concept design (Augmentation of explorative concept design 17 references; unstructured nature effective in exploration 10; versatility in generation of multiple choices 13). Interviewee

ST.01 described the relationship between concept design and the process of sketching. Suggesting the use of the tool in support of thinking about initial ideas, he described how sketching is characterised by a less defined embodiment:

Concept design would be just sketching. Sitting and drawing. Sort of working drawings and sketches for myself rather than deep down nice, neat drawings. Often really rough drawn on top of one another, heavily annotated.

(Interviewee St.01)

In contrast Pr.06 discussed 3D CAD as constraining in its ability to support the kinds of divergent, less defined design embodiment considered valuable during conceptual design activity:

More constricting because you would have spent so much time designing the components, going down a particular rout; designing the components in a particular way.

(Interviewee Pr.06)

The designers often discussed hand sketching in terms of 3D CAD in order to emphasise a contrast in the two tools. This was at its most noticeable during conversation relating to the implications of the constraining and convergent character of CAD against a more flexible, explorative divergent process of hand sketching:

So the first stage (indicating concept design) should be wider rather than stop on one or two of the designers. Because, the first initial stage, when you explore, should be more creative I think then you find the compromise rather than just the first ideas and then into 3D.

(Pr.03)

CAD's constraining feature often extended to the kinds of design activity supported through the use of the tool when compared with hand sketching. Designer Pr.06 describes 3D CAD's influence upon the practitioner's relationship with design embodiment and reflection upon design ideas:

Maybe it would have been a hindrance rather than a tool because you were kind of then in a certain pattern of thinking.

(Pr.06)

Pr.02 seemed to echo this sentiment, describing the tool as a constraint on design thinking:

It can be constraining in terms of flexibility and speed at which you can churn out concepts. Because, especially, if you go down the 3D route, you got a lot of constraint on figuring out.

(Pr.02)

Hand sketching was generally discussed more positively, with the designers wishing to emphasise the affordance of sketching against the constraints of 3D CAD, often citing sketching's unstructured nature and ability to support conceptual design thinking through exploration (Theme of Discussion classified under divergence, Figure 8.10). Conversation on hand sketching indicated a belief in the inherent effectiveness of the tool, something that made the tool particularly useful to design activity. Concern over 3D CAD also appeared to stem from concern that sketching might be marginalised due to an increasing reliance upon 3D CAD tools (Pr.02, Pr.06).

Discussion of 3D CAD in terms of convergent specification was often contrasted with the designers' view of hand sketching as a more flexible and unstructured medium of embodiment. This may be evidence of the relationship between the context of the wider process of design and the mediating tools used in support of the various requirements of practice. The designer must consider the contradictory requirements of divergent iteration and convergent specification which are both characteristics of the industrial design process. Findings indicated that 3D CAD tends to be used in design activity that may be weighted towards specification, with hand sketching often used to support divergent exploration. This is evidence to suggest the singular influence of the tool-in-hand as it is used to support design activity. However, an understanding of the rich and complex contexts (practice) that inform tool use is no less significant. However, the fact that designers also discussed the use of sketching during detail design and CAD in support of concept design, the results also indicates the influence of the designer's idiosyncratic approach to practice and the use of design tools.

8.1.5 Support of Detail and Development Design

Discussion of the tool's support of detail (3D CAD) and development design (hand sketching) related to the influence of design process (rules & conventions of design

process, Figure 8.11) as they inform tool use. Evidence of the influence of these wider contexts were absent within the survey study (Chapter 7), but clearly informed the designers' discussion of tool use.

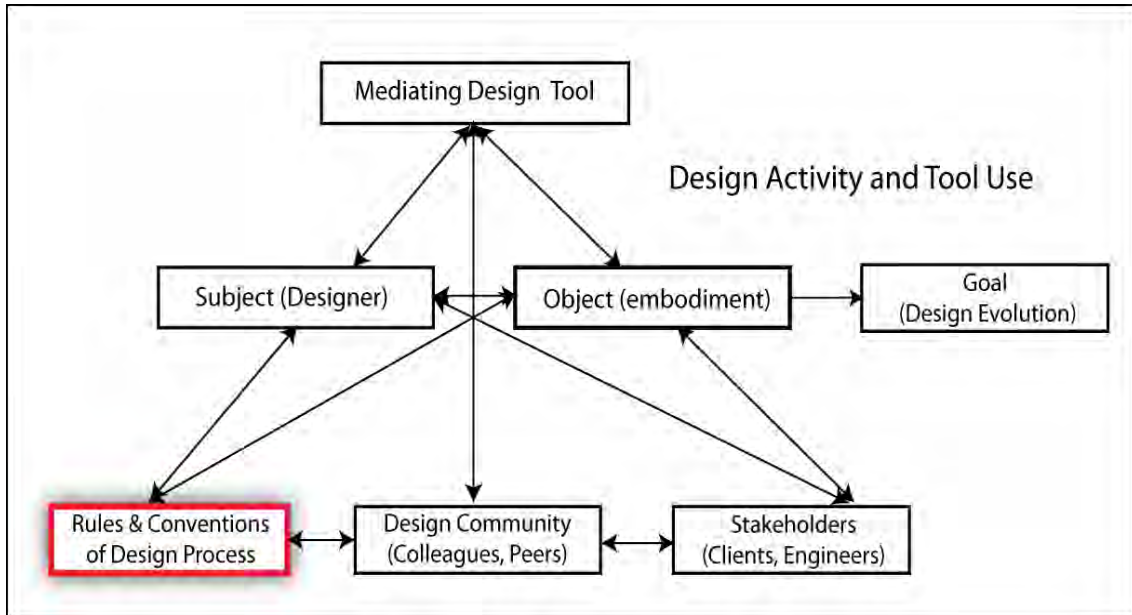


Figure 8.11 Role of detail and Development Design within model of design activity

Figure 8.12 illustrates results for the two Topics of Conversation. The topics identified conversation on the relationship between the use of the two tools and the influence of the requirement to convergent detail (3D CAD) or more divergent/convergent development design (hand sketching):

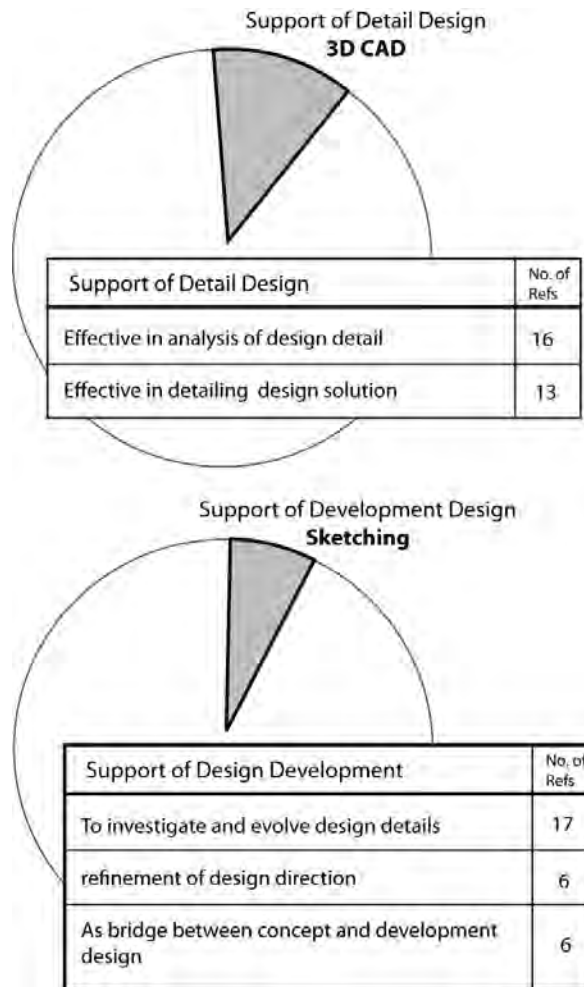


Figure 8.12 Topics of Conversation Support of Detail Design & Support of Development Design, two Theme of Discussion cited for 3D CAD, three for hand sketching

As well as being discussed in terms of its support for divergent concept design, sketching was considered effective in the progression of the design process from concept through to development design (Themes of Discussion, Figure 8.12). When discussing the affordances of CAD tools, designers suggested a tendency to use them in the more specific definition of design intent:

To Prove that all the components fit within our design and the size it will probably only vary about ten percent (3D CAD)

(Interviewee Pr.02)

Pr.02 described CAD's ability to foster confidence in design proposals through increasing specification of intent. In contrast, hand sketching was often discussed in

terms of its ability to avoid such specification, instead being used to explore design intentions during a divergent concept design process:

So 3D (CAD) is important but hand sketch is not just a bonus it's the way to, anyway to [stressing 'anyway'] the first filtering down from the concept.

(Interviewee Pr.03)

Discussion of 3D CAD described its use in the confirmation of design intent. The designers spoke of the tool's ability to foster confidence in the feasibility of concept ideas. This was particularly true for designer Pr.02, whose consultancy had coined the term 'blobs' for the use of design embodiment through 3D CAD when used during concept validation:

More and more so now we generally sketch, foam, and then do some loose 3D, which we call 'blobs' essentially. They're without much detail. They describe the overall form and main elements.

(Pr.02)

Discussion of hand sketching often cited the tool's effectiveness at a front, conceptual end of studio practice. Less intuitively, but in agreement with survey findings (Chapter 7, hand sketching), designers considered sketching effective in the exploration of design detail:

I've used sketching during detail design, but it's perhaps more, I hate to say it, but perhaps more trivial detail design. Um, you have things like putting ribs on the outside of a product. If they look better angular or pitted.

(Pr.06)

Here, the designer's perception of the sketch seems to have influence upon its use for 'more trivial detail design', the embodiment of design intentions that appear less defined and more 'trivial'. For interviewee St.09, a design student with less experience of practice, the use of hand sketching was limited to concept design, and only then used as a precursor to 3D CAD. The influence of designer St.09's level of experience had implications for the tool's use in practice. This would agree with the survey findings, indicating the influence of expertise on the designer's engagement with design tools and how this is a reflection of the designer's own approach to practice (Chapter 7). Discussion of 3D CAD indicated its use in development and detail design for a, 'deeper

understanding of the detail of design intentions'. Hand sketching was regarded as more effective during conceptual design due to its ability to support a more iterative exploration of the design problem.

Results suggested that tool choice and use is influenced by perceptions of what the designers see as the requirements of the design process and the tool's ability to meet those requirements.

8.1.6 Confirmation of Concept (3D CAD) and Inability to Communicate Reality (hand sketch)

Figure 8.13 illustrates how the two topics may relate to the Model of Design Activity in Tool Use. Discussion coded under the two topics indicated the interviewees considered both were related to a requirement for the design embodiment to communicate design intent in a way that will provide confidence in the proposed design and communicate realistic design ideas to others:

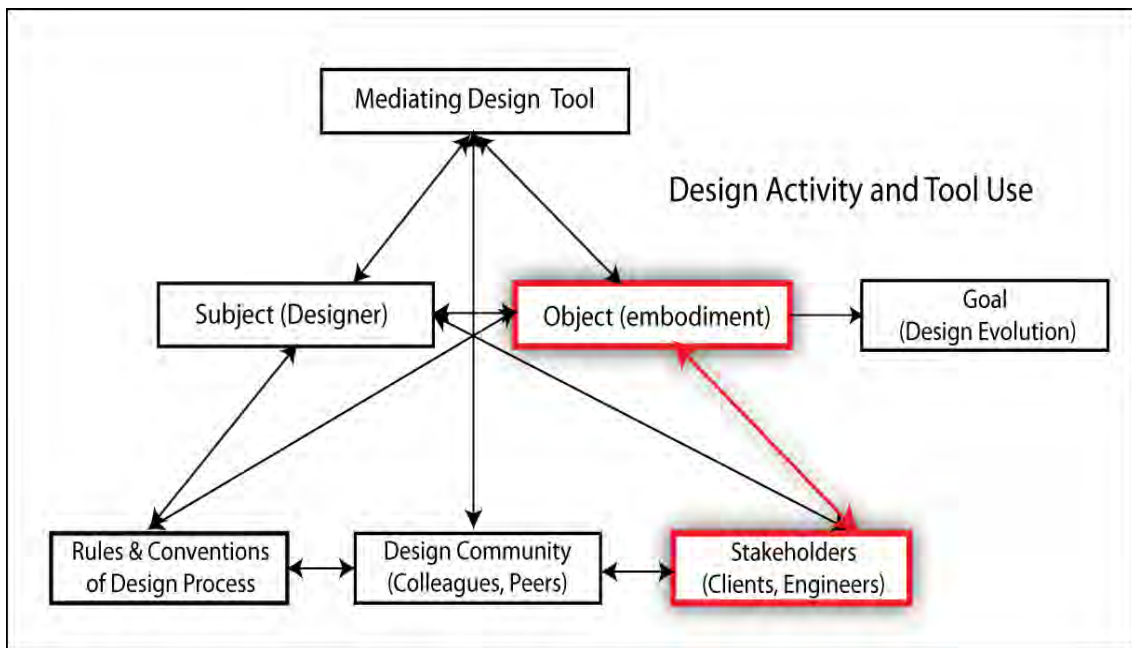


Figure 8.13 Role of Confirmation of Concept and Inability to Communicate Reality within model of design activity

Figure 8.14 presents results for the Topics of Conversation; Confirmation of Concept (CAD) and Inability to Communicate Reality (hand sketching).

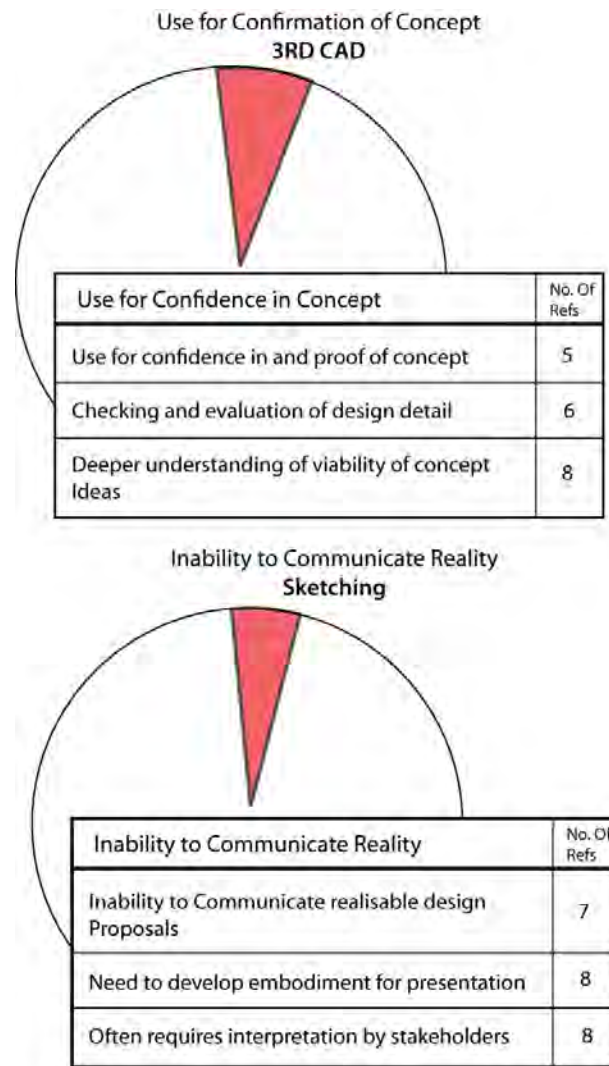


Figure 8.14 Topics of Conversation: confirmation of Concept and inability to Communicate reality. Three Themes of discussion cited for 3D CAD and hand sketching

The Topic of Conversation ‘Inability to Communicate Reality’ (Figure 8.14) relating to sketching inability to realistically communicate design intentions. In contrast, discussion of 3D CAD indicated its effectiveness in providing confidence in the concept ideas through their embodiment. Designer Pr.04 discussed the use of 3D CAD as a means to embody design intent in a way that provided reassurance and validity to design ideas, previously embodied as sketches:

Say if you had your preferred idea, you might spend a short amount of time, half an hour or an hour perhaps at the most, just drawing that up in 3D [CAD] to really sort of reassure yourself that's not, in terms of scale, it's going to work.

(Interviewee Pr.04)

Pr.04 spoke of his tendency to move between hand sketching and 3D CAD during design practice, making the most of what he perceived as CAD's affording attributes and sketching's ability to support divergent exploration.

These Topics of Conversation related to the requirement to progress design intention towards a realistic and achievable design solution which was then realised through a process of manufacture. Although hand sketching was identified as a means to explore design intent and, to a degree, develop and detail design solution ideas, 3D CAD was often discussed in terms of its ability to communicate viable design proposals. In contrast hand sketching was considered to be less able to communicate realizable proposals. This suggests the influence of the tool-in-hand on design activity.

8.1.7 Commitment to Design Intent (3D CAD) and Uncommitted Character (hand sketch)

The Topics of Conversation 'Commitment to Design Intent' (3D CAD) and 'Uncommitted Character' (hand sketching) clearly related to the UTC Levels of Commitment (Chapter 5). Figure 8.15 maps the two topics onto the model of design activity. Discussion suggested the influence of the character of design embodiment on the Level of Commitment (object embodiment); concern for the stakeholders' perception of commitment (stakeholders); and the ways the design process will influence how committed embodiments appear to be (Rules & Conventions of Design Process):

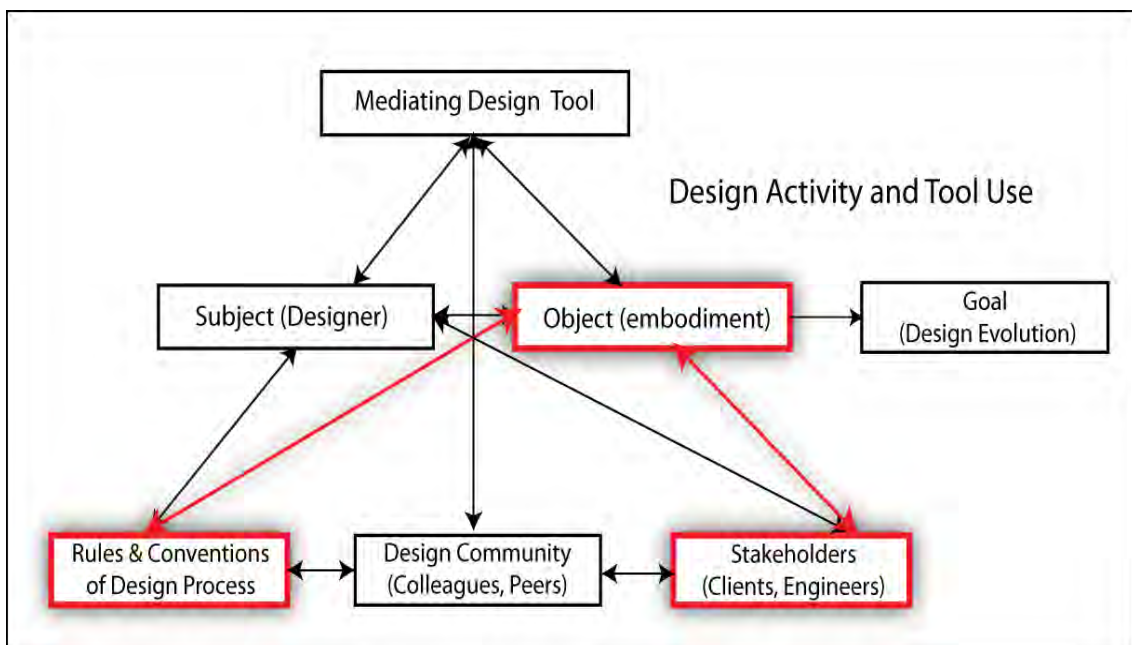


Figure 8.15 Role of Commitment to design intent and uncommitted Character within design

‘Commitment’ however is a subjective notion that could be influenced by all the principles within the model.

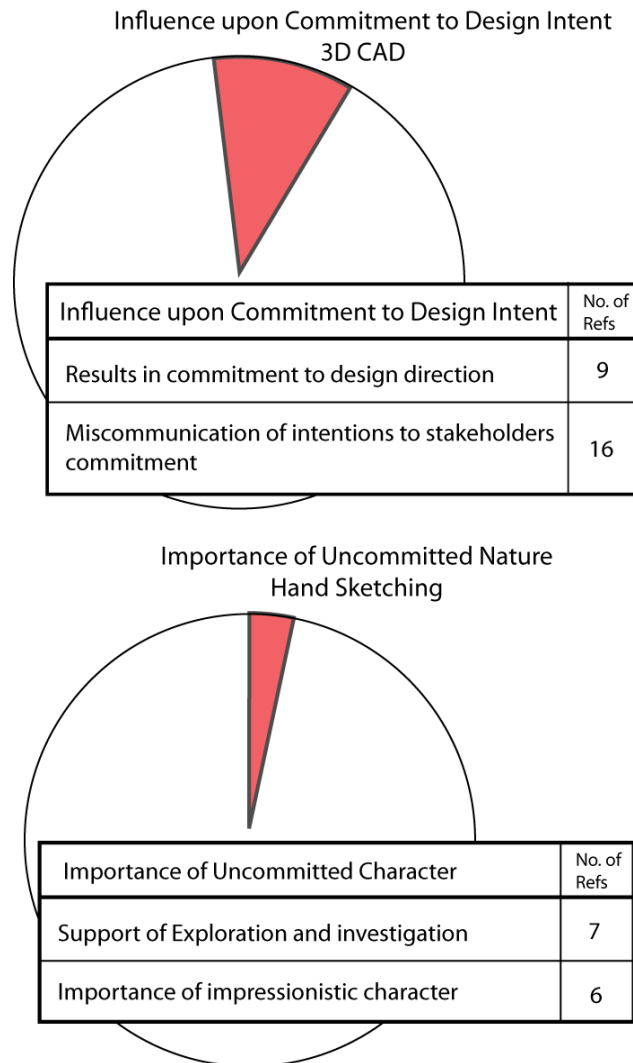


Figure 8.16 Topics of Conversation: Commitment to design Intent (3D CAD) & Uncommitted Character (hand sketching). Two Themes of Discussion cited for both 3D CAD and hand sketching

The Topic of Conversation ‘Commitment to Design Intent’ classified references to commitment when using 3D CAD tools. Designers described the use of 3D CAD as tending to communicate commitment to design intent when compared to hand sketching. This commitment to design proposals was often described as unwanted, as intentions were communicated to stakeholders in a way that indicated completion. The interviewees often compared CAD’s more committed character with that of hand

sketching's support of the impressionistic embodiment of design intent. Designer Pr.05 discussed the relationship between design embodiment through the use of the two tools and the communication of commitment during concept and development design:

We've been bitten before by showing things too raw in the sketch stage, where the client just doesn't get it. If the client is familiar with seeing the 3D CAD, they want that right at the early start of the process. The flip side of that is if you show them CAD too early they think that's it there's no development to do. They think the job's done.

(Interviewee Pr.05)

The designer articulated a concern over the tools' influence upon the communication of commitment and the ways this may influence client perceptions. A juxtaposition of one tool against the other was identified as the designer discussed the use of the two tools in the communication of intentionality, with CAD seen to move embodiment towards commitment and sketching used in support of the communication of less committed intentions. This provided evidence to indicate how the design tool's use during design embodiment relates to the requirement to consider the ways in which intentions are communicated.

8.1.8 Communication of Design Intent and Facilitator of Collaboration

Figure 8.17 attempts to map the two Topics of Conversation onto the model of design activity and tool use.

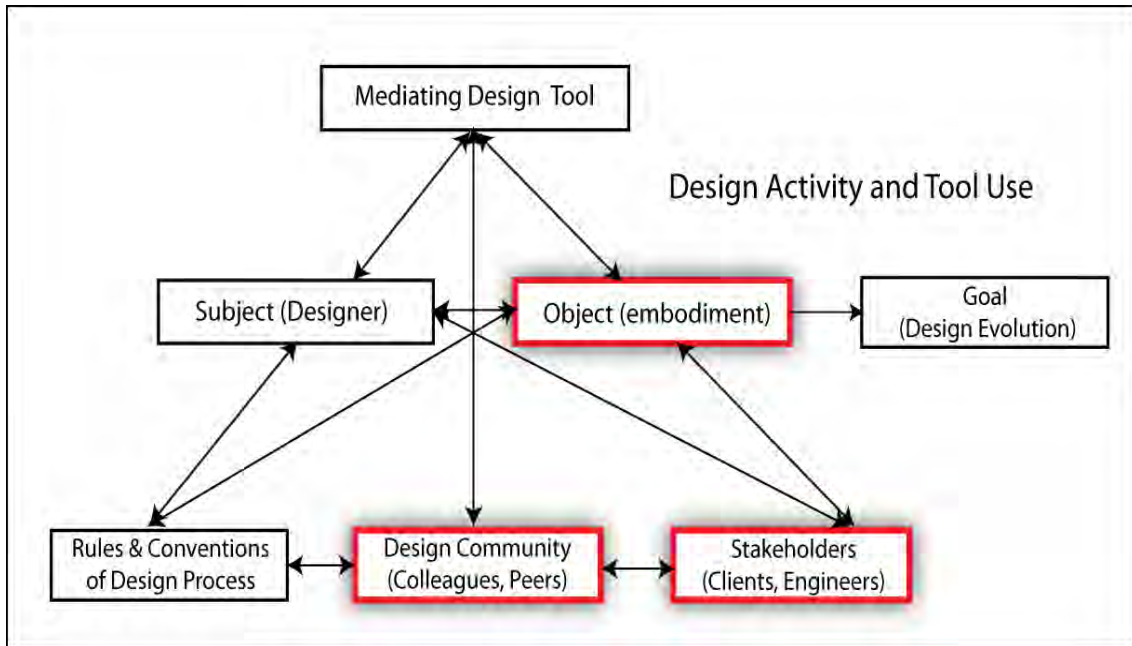


Figure 8.17 Role of Communication of Design intent and Collaboration within model of design activity

Discussion coded within 'Communication of Design Intent' (3D CAD) and 'Facilitator of Collaboration' (hand sketch) related to the tools' ability to foster collaboration, either internally to peers or externally to stakeholders. The topics suggested a relationship between design tool use and a requirement to communicate design ideas to others.

Figure 8.18 illustrates the Theme of Discussion classified under Communication of Design Intent (3D CAD) and Facilitator of Collaboration (hand sketching):

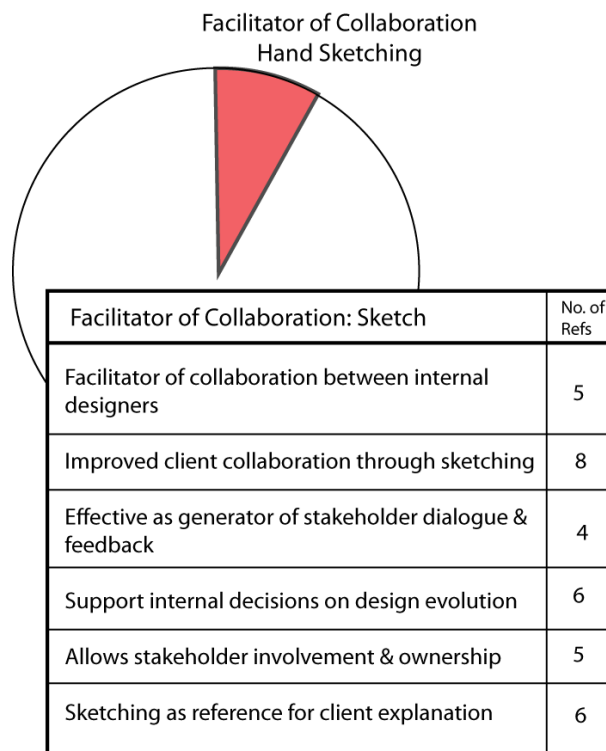
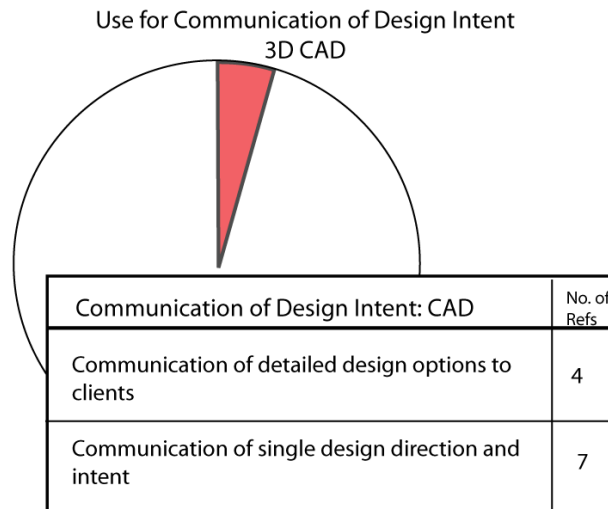


Figure 8.18 Topics of Conversation: Communication of Design Intent & Facilitator of Collaboration. Two Theme of Discussion cited for 3D CAD, six for hand sketching

The interview findings suggested contrasting attitudes towards the affordance of the two tools in terms of communication. Interviewees tended to consider hand sketching effective in collaboration between designers and stakeholders. The experimental nature of the design embodiment through sketching was cited as effective in this collaboration (Pr.05). However, this view was contradicted by other interviewees (Pr.04), who suggested that design embodiment, through sketching, was less able to communicate realisable design intentions and that this limited its use during client

presentation. Where interviewees discussed 3D CAD's ability to communicate intentions, it was often in terms of the communication of more specific design proposals.

Results indicated that designers held different attitudes towards the ways in which design tools could be used to support design communication and stakeholder involvement; as indicated in conversation around the tools' ability to communicate in different ways. Conversation relating to 3D CAD made references to its ability to communicate a design direction in the presentation of detail. However, discussion also suggested that designers felt the use of CAD could communicate more commitment to the design direction than was desired for a conceptual, divergent stage of practice.

If you show them CAD too early they think that's it, there's no development to do. They think the jobs done. What are we doing over the next two stages? Because we've shown it all up front. They have a problem in seeing.

(Pr.05)

With regards to hand sketching, a number of Themes of Discussion were identified that related to the tool's use for communication (Figure 8.18). Within these, its ability to facilitate client collaboration was identified as important:

It allows the client to engage. The client can see. The client can contribute. So they have that, sort of contribution, that feeling of ownership over any ideas. It becomes a collaborative stage of a project.

(Pr.05)

However, discussion on the use of sketching during collaboration also suggested its inability to communicate realistic or realisable design proposals which resulted in miscommunication and misunderstanding between designer and stakeholder. Pr04 voiced such concerns:

I mean a lot of people can sketch some beautiful things but they might not have a logic behind them that makes sense to the client. So you, again, you've got to use it based on facts.

(Pr.04)

In terms of 3D CAD, designers described the communication of a convergent, more detailed design direction, but that this may also cause problems in terms of the communication of design proposals that appear more committed. With regards to hand sketching, the designers felt that the tool was effective in supporting collaborative design, ‘allowing client involvement’ (Interviewee Pr.05). However, the designers also voiced concern over the less defined nature of sketching because of the perceived inability of the tool to communicate realisable design proposals. These results indicate a relationship between the mediating design tool; the kinds of design embodiments it is used to construct during design activity; and how they must necessarily relate to the requirements of communication at various stages of the design process. The designers’ differing attitudes towards the use of design tools, at different stages, indicated the influence the practitioner has over the ways in which this relationship plays out during studio practice.

8.1.9 Design Thinking and Reflective Design Activity (hand sketch)

A final two Topics of Conversation (both identified in discussion of hand sketching) related to the designer’s subjective Reflection-in-Action when using sketching tools. Support of design thinking and reflective design activity indicated a relationship between the designer and design embodiment to externalise, reflect on and evolve design intent (Figure 8.19):

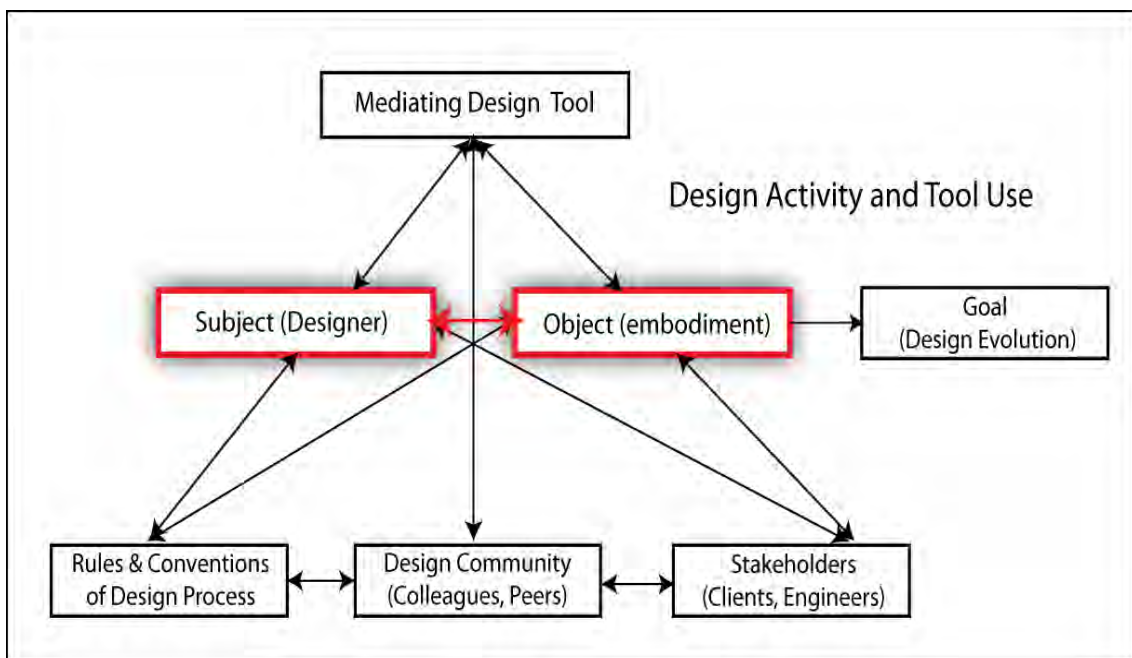


Figure 8.19 Role of Design Thinking and Reflective Design Activity within model of design activity

Figure 8.20 illustrates the breakdown of Theme of Discussion classified within the two topics:

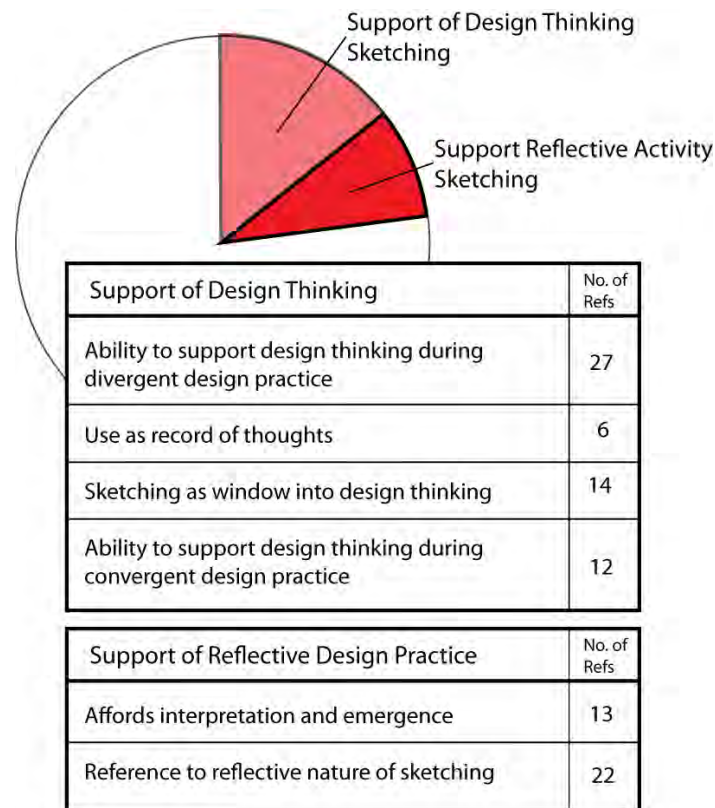


Figure 8.20 Topics of Conversation Support of Design Thinking (four cited Themes) & Reflective Design Activity (two cited Themes)

The topics relate to the designers' discussion of hand sketching in terms of its ability to support thinking and reflection upon the embodiment of design intentions. Designer Pr.06 spoke of the importance of the sketch as mediator of design proposals during concept and development design. Sketching, in particular, allowed the kinds of lateral exploration required to develop understanding of the design problem:

So we would sketch sometimes for days to try and come up with a different, you know, a range of configurations of components. It took, it had to be on paper rather than CAD because we just weren't sure how to do it.

(Pr.06)

Designer Pr.06 indicated the tool's support of thinking about the design problem

through the embodiment of a range of solution ideas: 'range of configurations of components'. Designer Pr.02 discussed the hand sketch as a tool for the externalisation of design thoughts in support of reflection and design evolution, 'It's literally sketching, for most people

It's literally transferring what's in your mind directly onto paper. It's a dump of your ideas'

(Interviewee Pr.02)

Unlike 3D CAD tools, the designers tended to discuss sketching in terms of its ability to support the thinking through of design options. These results related to the UTC Reflection-in-Action (Chapter 5) and also indicated the influence of the mediating design tool in the kinds of reflection afforded through its use. Designers did not speak of 3D CAD in the same way. It may be that hand sketching is particularly influential in its ability to support a kind of reflective and thoughtful design activity effective during divergent conceptual design. That engagement with CAD tools tends to support a different kind of reflection which may be of more use during the convergence of design intent and the greater specification of ideas. The results indicated a relationship between the mediating design tool, the kinds of embodiments made during design activity and the practitioners own engagements with tools. The kinds of reflective embodiment made will depend upon the design tool's character and also the ways in which the practitioner perceives the relationship between tool and design activity, i.e. the designers own habitual and idiosyncratic working methods.

8.2 Discussion

Designers considered the use of hand sketching and 3D CAD as influenced by the various requirements of studio practice as well as stakeholder expectations. Their use of the two tools was also influenced by their perceived ability to construct design embodiments that were best suited to communication at a given stage in the design process. Moreover, and related to this, designers described the importance of an understanding of the relationship between a tool's character and its ability to communicate design intentions. In terms of 3D CAD, this manifest itself in conversations concerned with the less experienced designer's inability to see 3D CAD as a tool to support design activity, instead allowing the tool to overly influence design work. This was also true of hand sketching, with designers expressing concern for the student's ability to use the tool for the purpose of design activity, i.e. for the exploration

of design intent or communication of proposals, rather than to merely express design intent.

Results indicated that designers spoke more about the influence of CAD's character than when discussing hand sketching. External influences and stakeholder expectations were cited as affecting design embodiment through CAD and hand sketching tools, as was the influence of designer expertise upon the effective use of the tools. When discussing hand sketching, designers tended to cite the tool's character, external influences and design expertise equally. This indicated that designers considered the character of 3D CAD as having a greater influence on the embodiment of design intentions compared to hand sketching. However, the designers' discussion of hand sketching also suggested how a lack of experience in practice may influence the practitioner's ability to understand the relationship between the kinds of embodiments made and how these must relate to the requirements of practice.

When discussing sketching, designers made reference to its impressionistic character and the ways this increased its effectiveness during concept design. When discussing both tools, the designers spoke of efficiencies of speed and, in contrast to conversation on the character of 3D CAD, the sketch's more intuitive nature.

An analysis of conversation on the designers' choice and use of the two tools during practice has shown contrasting and often polarised attitudes, often setting one tool against the other. This could indicate the use of 3D CAD and hand sketching in reasonably well defined roles, with the designers' fixed attitudes towards the affordance and limitations of the two tools. However, the results also suggested that designer attitudes towards choice and use of tools are critically affected by the designer's own working culture and background, as seen in contradictory attitudes towards sketching ability to support design communication (see all survey results, Chapter 7).

For both 3D CAD and hand sketching, designers often cited client requirements and expectations as an influence upon their choice and use of design tool. However, with regards to sketching, a number of other influences were discussed related to the various ways that the tool could be used to support communication. Designers made more references to external influences on the use of sketching compared to 3D CAD, such as stakeholder requirements and stage in design process. It is not clear why this may be, but it could suggest that designers see hand sketching as more susceptible to external influence. The tools malleability may also require designers to consider the

implications that various types of sketching have for communication of design intent. In contrast, the more defined and generic nature of 3D CAD may leave less room for interplay between client expectations and the kind of design embodiments presented. Designer expertise was identified as influencing the use of the two design tools. In terms of 3D CAD, designers cited the influence of inexperience as it informed the misunderstanding of tool use. This concern was also identified in discussions on hand sketching, where the designers spoke of an inability of less experienced designers to use design tools for the purpose of design practice. In the case of 3D CAD, designers expressed concern for the ability of students to manipulate the tool to best suit the purpose at hand; rather than being constrained by the tool's limitations. For hand sketching, a lack of confidence and attachment to concept were both suggested as influencing the tool's use in practice by student designers. Effectiveness was described as an understanding of how design embodiment relates to the rich and various requirements of studio practice and design communication.

Sketching was also discussed in terms of its capacity to provide insight into creative design ability. Designers spoke of personality and an opening-up of design thinking to critical appraisal through sketching, in contrast to generic design embodiment through 3D CAD tools. It could be the characteristics of sketching, as a tool to support creative design thinking and reflection-in-action, demand a particular kind of skill and competence in use. This then leads to design embodiment that is more insightful in its revelation of design ability.

Results indicated discussion of 3D CAD was often in terms of its effect upon development and detail design. Although discussion of sketching was often in terms of its influence on concept design, it was also described as effective in support of both development and detail design. Tools were discussed in terms of the kinds of design activity required at different stages in the design process, with convergent nature of CAD acting against a more divergent process of embodiment through hand sketching. Discussion of 3D CAD indicated its use as a tool to support design understanding through increasing embodiment of detail. A proofing of concept ideas and an ability to validate were discussed, as was its effective support of concept evolution. Sketching was spoken of in terms of its support of the generation and exploration of concept ideas as a bridge between concept and development design and during detail design in support of investigation and evolution of problem design details. The findings indicated the different ways in which the two tools supported and influenced studio practice. CAD

was more analytical and valedictory in contrast to sketching's perceived ability to augment a more explorative design activity.

The findings also suggested that 3D CAD has an influence on the level of commitment communicated to stakeholders. It was described as effective in the communication of a single or small number of design directions. Designer responses indicated that the use of 3D CAD might result in the over-committed communication of proposals. In contrast, sketching was described as effective in supporting collaboration between designer and stakeholder and supporting client involvement through its more open and uncommitted nature. However, designers also discussed sketching in terms of an inability to communicate realisable design intentions and that sketches produced to communicate intentionality were often altered before presentation. Although there was a tendency for designers to discuss 3D CAD in terms of convergent detail design and sketching in terms divergent design, differences in attitudes towards the use of the two tools also created contradictions within the sample. Some designers considered CAD unsuitable for conceptual design due to the way in which it may communicate unwanted commitment to design intent; others within the sample indicating CAD's use to support confirmation of concept during a generally more divergent, conceptual stage in practice.

Results indicated that there were certain affordances and constraints present in the implicit character of the two tools, which made them more or less effective at a given stage in practice (the influence of the tool-in-hand, see also survey results, Chapter 7). However, the designer's understanding of the relationship between tool and design activity, how they co-depend and relate in the context of the design process, will also critically influence the tool use.

Parallels were seen between the interview findings and those of the survey study (Chapter 7). The tool-in-hand will critically influence the kinds of embodiments made. External factors will also influence tool use (Stakeholder requirements, the need to progress design intent towards specification). Tool use is also informed by the designers approach to practice, given their awareness and understanding of these competing principles.

It is this awareness, fostered through experience of practice that informs the experienced practitioner's tendency towards openness and iteration; suppressing the influence of the design tool through an understanding of its role within a wider context of use.

Chapter Summary

The interview results indicated a variety of influences upon design tool use during studio practice: the influence of the tool-in-hand during design embodiment; contextual influences on tool use (a requirement to progress design intent towards specification, stakeholder requirements) and the designer's own influence on tool use.

In terms of the influence of the tool-in-hand, interviewees spoke of how the character of hand sketching and 3D CAD informed the kinds of embodiments made. Hand sketching was often described as supporting concept embodiment, 3D CAD effective in more specific embodiment (see also Chapter 7).

Contextual influences on tool use were also discussed (hand sketching's use during concept design, the use of 3D CAD to develop design intent and how the two tools influence the communication of design intent to stakeholders). This indicated a relationship between the tool-in-hand and the contextual requirements of design practice.

Findings suggested, as with the survey study (Chapter 7), the influence of the designer in their idiosyncratic approach to tool use. Although the interviewees discussed the relationship between the implicit affordances of both hand sketching and 3D CAD, they also stressed the ways in which the tool-user (designer) informs the tool's manipulation in response to various contextual requirements. For example, interviewees spoke of the importance of understanding the context of the use of hand sketching (stage in practice, stakeholder expectations) and to then employ the tool to best satisfy the contextual requirements. Interviewees described a lack of contextual awareness, due to lack of experience, as compounding the influence of the tool-in-hand. That is to say inexperienced designers are less likely to consider the influence of the tool-in-hand as it relates to the contexts of its use. Paradoxically, this ignorance was described as leading to the character of 3D CAD dominating the kinds of embodiments made (designs influenced by CAD software), and the use of hand sketching that did little to address the contextual requirements of its use (sketching for sketching sake, rather than sketching to design). Less experienced designers become concerned with the aesthetic of the sketch embodiment, leading to a lack of confidence in their sketch ability.

Less experienced designers require opportunities to develop understanding of how the tool-in-hand and contexts of tool use inform design activity. Through this understanding a more balanced approach to design activity and tool use may develop. This approach, taken by more experienced designers, involves a heightened awareness of the affordances and constraints of the tool in terms of the contexts of its use. This approach may suppress the influence of the design tool through a deeper understanding of how that influence exists as part of a wider context of use.

Chapter 9: Conclusions

This final Chapter discusses the study's key research findings and their ability to address the research objectives and answer the research questions presented in Chapter 1 (section 1.3). The study's primary contributions to knowledge is then discussed in terms of the research aim: to develop greater understanding of relationships between the character of various design tools, the designer's own idiosyncratic approach to tool use and the often dynamic and complex requirements of a process of industrial design (Chapter 1, section 1.3). Finally, possible directions for future research are considered.

9.1 First Research Objective & Research Question 1

A first research objective sought to establish current understanding of design tool use during industrial design practice:

To explore the state-of-the-art in terms of current knowledge and understanding of design tool use during industrial design practice with the objective of informing a study of tool use and locating it within an existing body of work.

In order to fulfill this first objective, research question 1 aimed to review existing literature focused on understanding design tools and their use in support of design activity:

1. What are the pre-existing principles, influences and conventions that inform understanding of design tool use in the embodiment of design intent during studio practice?

The literature review led to a number of key findings. These findings were then used to inform models of design process and design activity, a taxonomy and identification of UTCs:

- Existing studies described a staged approach to the industrial design process. This informed a simplified 3 stage model of process, progressing from concept through development and finally on to detail design (Chapter 3).
- Activity theory was used as a framework for the investigation of tool use during design activity (Chapter 3).
- The literature review informed a taxonomy of design tools based upon the simplified 3 stage model of industrial design process (Chapter 4).
- 5 UTCs were identified. these were used to analyse designer attitudes towards design tool use (Chapter 5).

These outcomes suggested some of the pre-existing principles that inform understanding of design tool use for the embodiment of design intent during practice. They were then used to address a second research objective.

9.2 Second Research Objective & Research Question 2

A second research objective related to the empirical investigation of designer attitudes towards tool use:

To investigate design tool use during design activity, using existing knowledge to inform the investigation.

In order to meet this objective, the research outcomes described above were used in the design and implementation of a primary research strategy to address research question 2:

2. How might pre-existing principles be further investigated and what emergent understanding may be gained through this investigation?

The taxonomy of design tools and UTCs were used to inform research methods and define a research strategy. These methods were considered to be the most effective in providing data to analyse attitudes towards tool use during design activity. Designer attitudes were measured against the tool's ability to support the UTCs described in Chapter 5 and findings were considered against the principles described in the Model of Design Activity and Tool Use presented in Chapter 3.

The results indicated relationships between the design tool and its place of use during the design process, as indicated by the taxonomy of design tools. Findings also suggested relationships between the mediating design tool, the kinds of embodiments made and the influence of the practitioner's existing working methods. The influence of practitioner experience seems to be significant as experience of practice influences the designer's approach to design activity and tool use, shown in the difference between student and practitioner results (survey study, Chapter 7).

A tension in attitudes towards hand sketching and 3D CAD tools was also identified as a result of designers' juxtaposing one against the other (Interview study, Chapter 8). This centred on a belief that 3D CAD is limiting in terms of divergent, conceptual design, but more effective in support of convergent development design. In contrast, hand sketching was considered more effective in divergent and conceptual design practice. However, results also indicated, the use of design tools is not only dependent on the stage in design practice at which the designer works, but on a richer mix of principles. Essentially it is the requirements of the design project, stakeholder expectations and the designer's working methods and approach to design activity, as determined by levels of expertise and experience of studio practice, that together influence tool use.

Experience of industrial design practice has a significant influence on attitudes towards design tools and the designer's approach to studio practice. The results relating to student designers has indicated less positive attitudes towards those characteristics of design activity often associated with divergence, iteration and exploration: lateral transformations between design ideas; reflection-in-action; ambiguity in the embodiment of design intent (Chapter 5). These findings indicated a tendency for student design activity to move towards the crystallisation of design intentions earlier

and more quickly. Practitioners, on the other hand, may tend to work in a way that supports divergence and iteration in the design activity for longer, as seen in their more positive attitudes towards divergent design. This was seen in practitioner attitudes towards design tools (sketch modelling, digital graphics tools, rapid prototyping) in their ability to support UTC often associated with divergent, explorative design activity (Mode of Communication: reflection-in-action, Transformational Ability, Level of Ambiguity).

Together with the influence of the tool user (the designer), the findings also indicated the importance of the implicit character of the tool-in-hand. Intuitively, results showed the ways in which the character of the tool influenced the kinds of embodiments made. For example, designer attitudes towards the use of rapid prototyping tools suggested their importance for convergent and specified design embodiment. Interestingly, results also suggested how design tools are manipulated to embody design intent for a variety of specific purposes at different stages in the design process. For example, hand sketching, more often associated with concept design activity, was used to support detail design practice and the exploration of problem areas (interview study, Chapter 8). And that this use of hand sketching might be more prevalent in the practice of experienced designers. 3D CAD was also shown to be used during concept design as a tool to assist in proof-of-concept, but that experienced designers may be less likely to become fixated through the use of CAD in this way. In contrast, less experienced designers may tend towards earlier fixation and attachment to concept when using tools, as seen in more positive attitudes towards those UTCs associated with convergent design (higher Level of Detail, higher Level of Commitment, less ambiguity and Reflection-in-Action during design embodiment, survey study Chapter 7). The tool-in-hand has influence upon the kinds of embodiments made, but design embodiment and tool use also depend on the designer's own engagement with design activity.

The results have indicated how the investigation of a relationship between design tool and design embodiment alone (often seen in design research) is insufficient in developing a holistic understanding of tool use during design practice. Although the results suggest that the relationship between the mediating design tool and the kinds of embodiments made is often critical, any investigation of this relationship needs also to account for both the practitioner's influence on tool use and the wider contexts within which design activity locates; the often dynamic requirements of the design process, stakeholder requirements, working methods within individual design practices.

9.3 Third Research Objective & Research Question 3

A third research objective sought to use the empirical investigation to develop new knowledge related to the use of design tools during design activity:

Through an investigation of design tool use, develop new knowledge related to the designer's use of design tools during design activity.

Research question 3 sought to consider to what extent the research findings met the objective of developing new knowledge and understanding of tool use during design activity:

3. What might this emergent understanding tell us about the practitioner's attitudes towards and use of design tools during studio practice?

The findings defined the highly dynamic relationship between design activity and the design process. From concept to detail design, practitioners engage in a fluid process, mixing convergence and divergence during design embodiment in reaction to the changing requirements of the design project.

Figure 9.1 illustrates the industrial design process as three stages (concept, development and detail design). Design divergence and convergence are also illustrated, with convergence increasing as divergence recedes and design progresses towards specification and manufacture. Design problems differ in character and complexity. Consequently, the relationship between divergent iteration and convergent specification will vary from project to project and especially in the approaches taken to the generation of solution ideas by designers with different backgrounds and levels of expertise. However, the model is effective in expressing the dynamic qualities of the design process as the activity moves between divergent, exploration and convergent specification.

Into this model, the use of design tools may be located in terms of where they are typically often employed to support practice. Figure 9.1 illustrates the use of three tools within the design process. The research results suggested that designers made use of hand sketching and 3D CAD throughout the design process in a variety of ways; although attitudes towards hand sketching suggested its place of often use during concept design, with 3D CAD most often employed during development and detail

design. In contrast, results indicate the use of other tools as limited to a particular area of the design process (Figure 9.1):

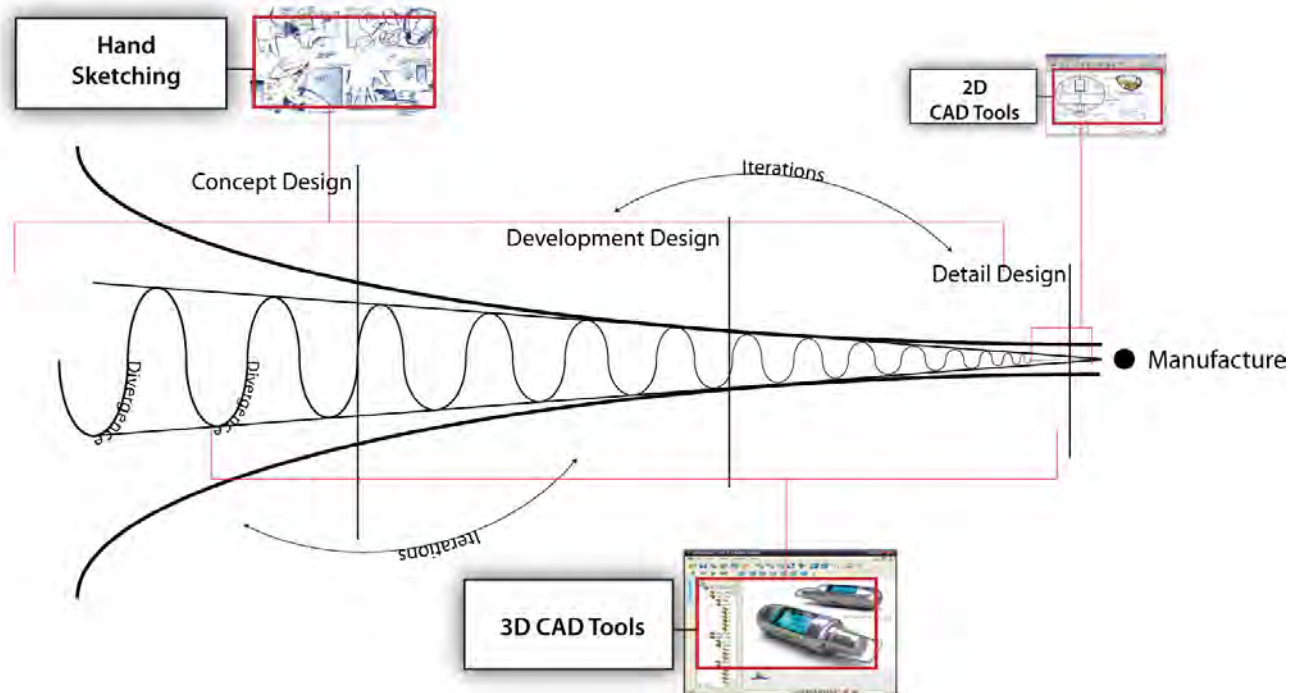


Figure 9.1 Model showing use of hand sketching, 2D and 3D CAD during design process

Design tools can be considered in terms of the relationship between tool and the design process (see taxonomy of design tools, Chapter 4). This description is effective in suggesting where tools tend to be used, but does little to consider why they may be used in such a way. This is because the connection between tool and process is therefore limited in its ability to describe other rich and complex relationships that inform the use of design tools in support of design practice: namely, the pragmatic and dynamic context of tool use (studio practice) and the idiosyncratic use of tools by individual designers.

The Model of Industrial Design Activity and Tool Use (Chapter 3) provided a means to consider the use of tools as part of this wider framework of co-dependent relationships. The key factors present in the model are summarised as:

- Design tools are located within a mutually informing framework which influences their use during the design process.

- This framework consists of the mediating design tool; object design embodiments made through the use of the tool; and the designer's own influence upon tool use.
- The activity of tool use is located within, and influenced by, the wider context of practice, its working norms, conventions and responsibilities.

Figure 9.2 is a Model of Industrial Design Activity and Tool Use, as presented in Chapter 3. The model indicates how the various principles; subject (practitioner), mediating tool (design tool) and object (embodiment) relate to inform tool use during design practice. A 'Point of Design Activity' is indicated (Figure 9.2), the point at which the various influences converge to inform tool use during design practice. Figure 9.2 illustrates the 5 UTCs (Chapter 5) as they emerge from these contextual principles that inform tool use during design activity:

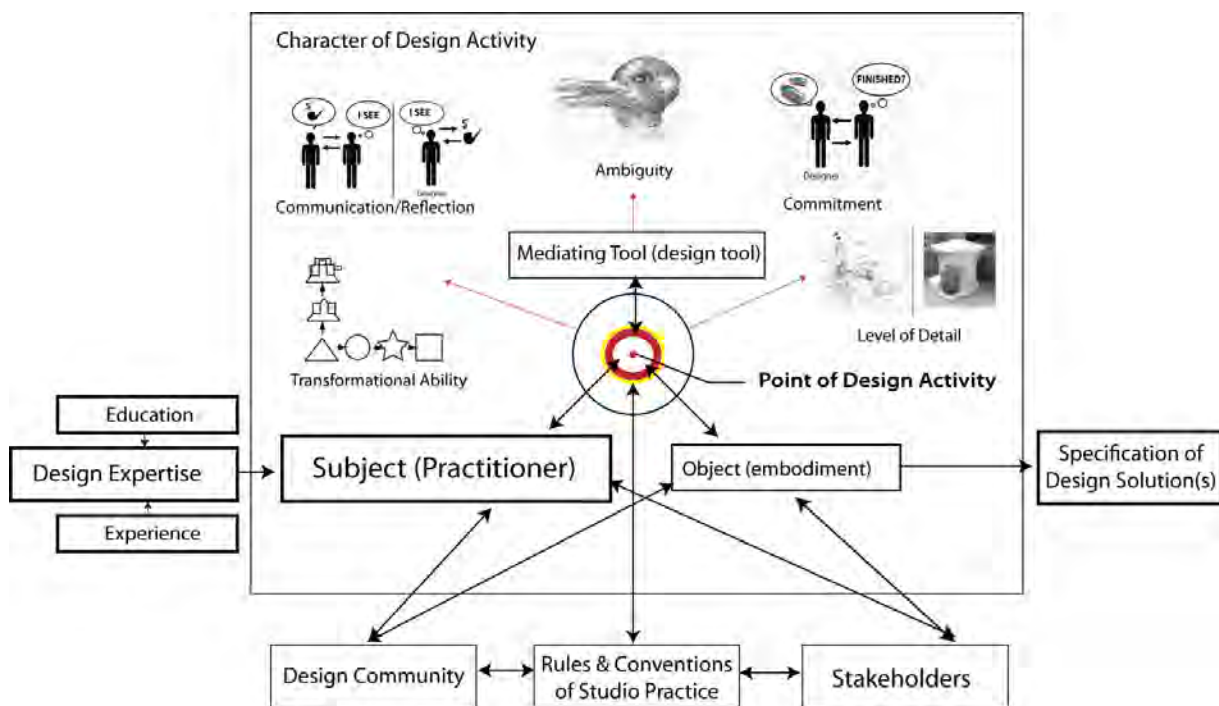


Figure 9.2 Model of industrial design activity and tool use including characteristics of design activity

Chapter 5 described the synthesis of 5 UTCs that were then used in the design of primary research strategies (Chapters 7 & 8). Rather than constituting a definitive description of design activity, the 5 UTCs served as a strategy to investigate attitudes towards tool use. Through an analysis of those attitudes, the relationships between some of the principles illustrated in Figure 9.2 were revealed. Findings from both a

survey and interview study indicated that the UTCs go some way to describe the design tool's ability to support practice. For example, those tools often used during divergent, concept design were considered to support the less detailed, ambiguous embodiment of design intent. However, the results also indicated the limitations of the characteristics in describing the design tool because of the rich and complex principles that converge to influence tool use (Figure 9.2). This research concludes that it is more appropriate to see the UTCs as emergent from a wider context of principles, rather than being the result of a given tool's use (illustrated in Figure 9.2). It is the designer's engagement with and understanding of these convergent principles that critically influences their approach to tool use, from a tendency to converge to an ability to remain more open to divergence and exploration.

Figure 9.3 includes the model of design process as it progresses through concept, development and detail design as critical in informing approaches taken to design tool use and design activity:

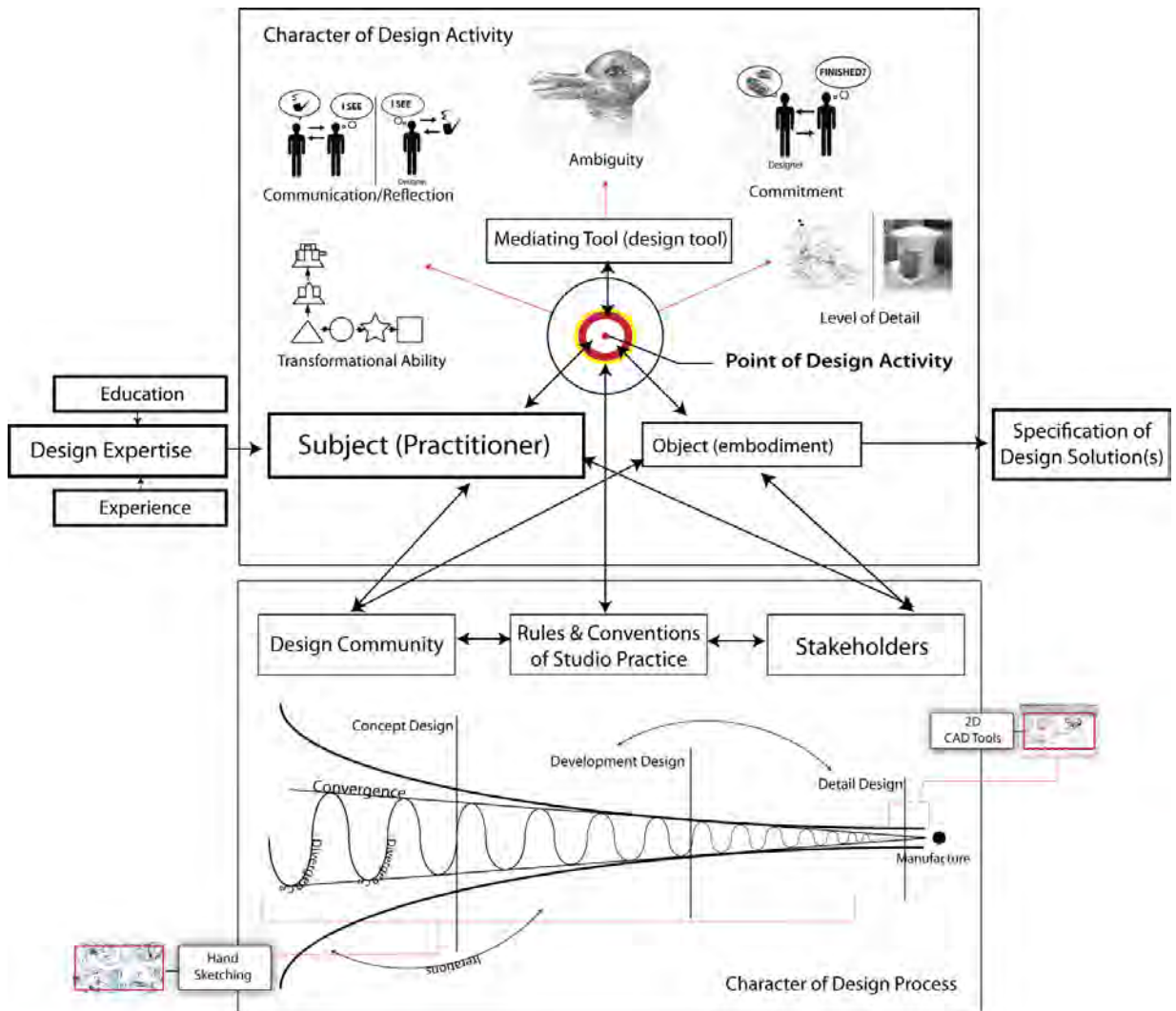


Figure 9.3 Model of Industrial Design Activity and Tool Use including design process

Figure 9.3 illustrates the idiosyncratic activity of the design practitioner within the top half of the model. This includes the relationship between subject (practitioner), object (embodiment) and mediating tool (design tool) and how these converge to influence the character of the point of design activity. Below this, the design process is presented as the background and wider contexts within which tool use takes place.

Engagement with and an understanding of each of the principles represented in the model above influences the practitioner’s own idiosyncratic approach to tool use during design practice and so the character of that practice: lateral and/or vertical transformation; to communicate design intent to other stakeholders and/or be used in a process of reflection-in-action; the amount of ambiguity in design embodiments and

commitment to design intent and the Level of Detail at which designs are embodied and communicated.

The Model of Design Activity and Tool Use together with the UTCs as a method to explore design tool use have some limitations. Although the research provided insight into some of the ways in which the principles within the model work together to inform the character of design activity (influence of the practitioner, the implicit influence of the tool-in-hand, the requirements of the design process, see Chapter 7), the description of the principles themselves and their weighting of influence, suffer from a lack of empirical research. It is hoped that this relational description of industrial design activity, and tool use within it, will provide a framework for future investigation, building upon the study's own results and further developing understanding of design activity and the critical use of design tools. This then provides an opportunity to identify other characteristics of design activity and consider how the model's principles influence these characteristics. This will then begin to provide a more holistic understanding of tool use during design activity.

In contemporary design practice, that sees an ever increasing selection of digital and hybrid tools available to the design practitioner, this research is a timely contribution to knowledge. This study has value as a framework for understanding fundamental principles of tool use and their role in support of design activity. This may then be employed in design pedagogy and the future development of design tools.

9.4 Fourth Research Objective & Research Question 4

A fourth research objective was to communicate research findings to an audience of designers, design educators and the design research community:

To disseminate new knowledge and understanding of design tool use to design practitioners, design educators and the design research community through conference papers, academic journals and the development of a digital resource (IDsite, Appendix O).

As well as conventional research dissemination, articulated through conference papers and academic journals, research question 4 considered the communication of results to engage a practice orientated audience:

4. How might research findings be best communicated to practicing designers to foster a more critical engagement with design tools?

Based upon research findings an interactive design tool, IDsite (Appendix O), was designed, constructed and prototyped. IDsite attempted to embody the research findings in a way that would engage a practice based audience to support their use of tools during studio practice, through greater awareness of the context of tool use.

After piloting IDsite, a revised version was validated through a 2-phase appraisal: a survey of experienced design practitioners and related professionals and a focus group of undergraduate design students. Findings indicated both sample groups held positive attitudes towards IDsite, suggesting the site's use was an effective means to support the design practice of student and novice designers and the validated IDsite as a tool to support tool use during design practice (Appendix O).

Through the explicit description of relationships between the character of design tools, the skills and experience of the practicing designer and the different requirements of practice, designers will be better placed to make more informed choices in their use of tools, reflecting upon their own approach to practice. This more critical engagement may work as a catalyst for objective working methods, better able to see tool and design activity as embedded within wider principles. And in so doing, develop an approach to practice that maximise the effectiveness of design tools while understanding their constraints and limitations. IDsite begins to achieve this through communication of results that exploited the visual language of design to engage an audience of design practitioners.

9.5 Reliability of Results

The research was not without limitations. Although the survey samples of students and practitioners were large (116 practitioners, 106 student responses), response rates varied due to the online nature of the practitioner survey (high student and lower practitioner responses, see Chapter 6). The practitioner responses may be less reliable in that only the practitioners with a particular interest in the subject of investigation took the time to respond to requests to complete a survey.

A further concern related to the strength of the relationship between what designers say of their attitudes towards design tool use, in the context of a survey or interview,

and how they actually use tools to support their design practice. The study's aim was to identify and analysis some of the various influences that serve to underpin tool use during practice, through investigation of the designer's attitudes towards tool use. As such, observations or protocol analysis was rejected as a means to analysing these underlying beliefs.

These concerns notwithstanding, the author feels the collection, analysis and presentation of findings were founded upon acknowledged social science research methods (Chapter 6, Research Methods). Coding of data was documented and research results presented and discussed using established presentation techniques (Chapters 7 & 8). This resulted in an indication of designer attitudes towards design tools. This in turn was used to suggest the designer's approach to design practice and how this related to their use of tools. Moreover, results indicated the ways in which design expertise critically influences both approaches to design activity and tool use.

In this way, this research has, within the limitations described above, provided new insight into the contextual influences that underpin tool use during industrial design practice. Specifically, it has identified some of the principles that underpin tool use and structured these using an adapted model of activity theory. In particular it has indicated a relationship between the character of design activity (from divergent exploration to convergent specification) and the designer's level of expertise. With experience of practice, the character of activity alters. This change appears to be influenced by an awareness of and engagement with the rich and complex contextual requirements of the design process. Design tools are employed in a way that reflects the designer's own knowledge and understanding of these contextual requirements.

9.6 Meeting the Research Aim & Contribution to Knowledge

The study aimed to come to a greater understanding of relationships between the character of various design tools, the designer's own idiosyncratic approach to tool use and the often dynamic and complex requirements of the industrial design process.

Through the exploration of designer attitudes towards their choice and use of tools (Chapters 7 & 8), the study has provided insight into the ways in which the designer's approach to design activity may inform tool use. This new insight contributes to an understanding of how the designer's approaches to activity and the use of various tools in the embodiment of design intent, relates to the designer's awareness of and

engagement with the rich and often dynamic requirements of a process of industrial design.

This research has relevance for industrial design practitioners, industrial and product design students, academics, educators, design researchers and other related professionals involved in the industrial design process and new product development. The contributions to knowledge derived from this study are as follows.

1. The research investigated the use of design tools in support of studio practice. Existing studies have taken a linear approach that focused on the relationship between design tool and object embodiment. The findings from the investigation of designer attitudes have gone beyond existing research to suggest a variety of related influences and their convergence to inform design tool use during practice. Specifically, the relationship between the designer's idiosyncratic approach to design practice and use of tools; the influence of the tool-in-hand and how these relate to the embodiments made and the ways in which design intent is communicated. This relationship exists within the context of the external influences of a design process that must progress from divergent exploration to convergent specification. This description has the potential to act as a framework for future investigation of design activity, tool use and the contextual influences that inform it. This is a contribution to knowledge.
2. The study has synthesised existing research related to design tool use during practice. This synthesis led to the description of 5 UTCs (Universal Tool Characteristics). Based upon empirical findings these were then used to describe the universal characteristics of design activity. The synthesis of the UTCs, and their use to measure the character of design activity, provided a means to investigation attitudes towards tool use. This showed both the influence of the tool-in-hand and the ways in which the designer's expertise influences how the tool is used to support a more divergent (design practitioners) or convergent (design students) approach to design practice. The use of the UTCs to investigate design attitudes towards tool use is an original contribution to knowledge.
3. Results made explicit the critical influence practitioner experience played in informing attitudes towards tool use and approaches to practice. Findings

indicated the ways in which these attitudes are a reflection of existing approaches to practice. Student designers tending towards a more constrained, convergent approach that may lead to earlier fixation and the crystallisation of concept ideas. More experienced practitioners tend to take a more explorative, divergent and often iterative approach to design work, allowing their design activity to remain open to suggestion and revision. Evidence of these different approaches was made explicit through more negative attitudes (students) towards those UTCs often associated with divergent conceptual design, compared to more positive practitioner attitudes towards characteristics associated with convergent design activity. Results indicated these pre-existing approaches to studio practice are compounded through the use of certain design tools (sketch modelling, 3D printing 3D CAD). These differences relate to an awareness of the tool's context of use within design practice. The explicit description of the relationship between designer expertise, tool use and approaches to industrial design practice, in terms of attitudes towards UTCs, is a contribution to knowledge.

4. The research has presented a relational model of design tool use during design practice. This model provides a framework for the study of design tools, design embodiment and the wider contexts within which design activity takes place. Further research, using the UTCs and the Model of Design Activity and Tool Use, will provide a means of relating the character of design activity (UTCs) to the various influences, principles and conventions that exist to critically inform it (Model of Design Activity and Tool Use). This framework has the potential to provide a more informed understanding of design tool use during practice: the ways in which the tool-in-hand influences design activity and how the designer's idiosyncratic approach influences tool use. With an increasing variety of digital and hybrid tools available to the designer, this is a timely contribution to knowledge. This is the study's primary value.

9.7 Future Research

In attempting to address the research questions a framework to inform the study of design tool use was described. The future application of the framework will provide opportunity for the continued development of the approach to the study of tool use

during design practice. This improved knowledge and understanding may then be used in design education to support the studio practice of industrial designers through an enhanced awareness and more critical engagement when using design tools in the embodiment of design intent.

Further research, based upon the principals presented in the framework, have the potential to provide a more holistic understanding of tool use and its relationship to design practice. When used in conjunction with the identified universal characteristics of activity (UTCs, Chapter 5), investigation of the weightings of influence within the framework's principles will provide a means of relating the character of activity to the various influences, principles and conventions that exist to critically inform it. The framework has the potential to help underpin future investigations and in doing, provide a more informed understanding of design activity and tool use.

Finally, the study has attempted to embed research findings within an interactive, web-based design tool, IDsite (Appendix O). In order to improve IDsite and its ability to communicate research outcomes in a way that is relevant and accessible to a practice orientated audience, the tool requires continued evolution. However the web-based approach to the site's construction, make its dynamic evolution not only possible, but a strength in its ability to evolve in response to further research findings.

References

Web

BUTLER, S (2004) The Note-Books of Samuel Butler [Homepage of Transcribed from the 1912 A. C. Fifield edition by David Price], [Online]. Available: <http://www.gutenberg.org/dirs/etext04/nbsb10h.htm> [accessed 5/7/10].

CORE77 ONLINE INDUSTRIAL DESIGN MAGAZINE (2010) [Homepage of Core77]. Available: <http://www.core77.com/> [accessed 06/06/09].

THE DESIGN COUNCIL (2010) Introducing Product Design [Homepage of The Design Council], [Online]. Available: <http://www.designcouncil.org.uk/about-design/Types-of-design/Product-design/Introducing-product-design/> [accessed 03/30/08].

DESIGN RESEARCH SOCIETY (2011) Available: <http://www.designresearchsociety.org/joomla/index.php> [accessed 06/06/11]

ELECTRONICS IN SCHOOLS LTD (2011) Modelling ECT Products. Available: <http://www.ectinschools.org/page.php?m=249&ps=212&p=758> [accessed 01/09/11]

INDUSTRIAL DESIGN: DEFINED (2010) last update. Available: <http://www.idsa.org/content/content1/industrial-design-defined> [accessed 08/10/10].

IDEO METHODS CARDS (2010) [Homepage of IDEO]. Available: <http://www.ideo.com/work/method-cards/> [accessed 8/23/10].

NORMAN, D (2011) Why Design Education Must Change. Corr77. Available: http://www.core77.com/blog/columns/why_design_education_must_change_17993.asp [accessed 5/06/11]

NUGENT, S (2010) last update, idsketching. Available: <http://www.idsketching.com/> [accessed 12/12/10].

NUGENT, S (2010), Sketch-a-Day. Available: <http://www.sketch-a-day.com/> [accessed 11/10/10].

POWELL, D (2007) Product Design: The essentials of Product Design [Homepage of Design Research Council], [Online]. Available: <http://www.designcouncil.org.uk/en/About-Design/Design-Disciplines/Product-design/> [accessed 04.03/08].

THE DIRECTORY OF DESIGN CONSULTANTS (2009) Available: <http://www.designdirectory.co.uk/> [accessed 10/06/09].

SENSABLE TECHNOLOGIES LTD (2008). Available: <http://www.sensable.com/> [accessed 10/06/08].

Print

ALMENDRA, R. and CHRISTIAANS, H. (2009) Improving design processes through better Decision-Making: an experiment with a decision making support tool, *IASDR09 relevance and Rigour*, 18-22 Oct 2009 2009, iasdr.

ARCHER, L.B. (1965) *Systematic Method for Designers*. London: The Design Council.

ARGUMENT, L., LETTICE, F. and BHAMRA, T. (1998) Environmentally conscious design: matching industry requirements with academic research. *Design Studies*, 19(1), pp. 63-80.

BABER, C. (2003) *Cognition and Tool Use: Forms of Engagement in Human and Animal Use of Tools*. first edn. London: Taylor & Francis.

BADKE-SCHAUB, P. and FRANKENBERGER, E. (2004) Design Representations in Critical Situations of Product Development. In: G. GOLDSCHMIDT and W. PORTER, eds, *Design Representation*. pp. 105-126.

BAXTER, M (1995) *Product design: Practical methods for the systematic development of new products*. London: Chapman & Hall.

BELLAMY, R. (2001) Designing Educational Technology: Computer-Mediated Change. In: B. NARDI, ed, *Context and Consciousness: Activity theory and human-computer interaction*. 1ed edn. cambridge, Mass: MIT Press, pp. 123-146.

BILDA, Z. and DEMIRKAN, H. (2003) An insight on designers' sketching activities in traditional versus digital media. *Design Studies*, 24(1), pp. 27-50.

- BRERETON, M. (2004) Distributed Cognition in Engineering Design: Negotiating between Abstract and Material Representations. In: G. GOLDSCHMIDT and W. PORTER, eds, *Design Representation*. London: Springer, pp. 83-103.
- BRYMAN, A. (2008) *Social Research Methods*. 3rd edn. Oxford: Oxford University Press.
- CHRISTIANSEN, E. (2001) Tamed by a Rose: Computers as Tools in Human Activity. In: B. NARDI, ed, *Context and Consciousness: Activity theory and human-computer interaction*. 1ed edn. Cambridge, Mass: MIT Press, pp. 175-198.
- Cohen, L et al (2007) *Research Methods in Education*. 6th ed. London. Routledge.
- CONRAN, T. (1996) *Terence Conran on design*. London. Conran Octopus Ltd.
- COYNE, R., PARK, H. and WISZNIEWSKI, D. (2002) Design devices: digital drawing and the pursuit of difference. *Design Studies*, 23(3), pp. 263-286.
- CROSS, N. (2007) *Designerly Ways of Knowing*. Basel: Birkhauser.
- CROSS, N. (2008) *Engineering Design Methods: Strategies for product design*. 4th edn. Chichester: John Wiley & Sons.
- CROSS, N. (1999) Design Research: A Disciplined Conversation. *Design Issues*, 15(2), pp. 5-10.
- CROSS, N. (1992) *Design Principles and Practice Block 1 An introduction to design*. Milton Keynes: Open University Press.
- CROSS, N., CHRISTIAANS, H. and DORST, K. (1996) *Analysing Design Activity*. Chichester: Wiley.
- DAHL, D.W., CHATTOPADHYAY, A. and GORN, G.J. (2001) The importance of visualisation in concept design. *Design Studies*, 22(1), pp. 5-26.
- DANT, T. (1999) *Material Culture in the Social World*. 1st edn. Ballmoor: Open University Press.
- DE VAUS, D. (1996) *Surveys in Social Research*. fourth edn. London: UCL Press Ltd.

- DENSCOMBE, M. (2003) *The good research guide : for small-scale social research projects* 2nd edn. Maidenhead: Open University Press.
- DESIGN COUNCIL (2007) *Eleven lessons: Managing design in eleven global companies.*
- DORISH, P. (2001) *Where the Action is: The foundations of embodied interaction.* London: MIT Press.
- DORMER, P. (1993) *Design Since 1945.* London: Thames & Hudson.
- DORST, K. (2007) Design research: a revolution-waiting-to-happen. *Design Studies*, 29(1), pp. 4-11.
- DORST, K. (2006) *Understaanding Design: 175 Reflections on Being a Designer.* 2nd edn. Amsterdam: BIS Publishers.
- DORTA, T. PÉREZ, E. and LESAGE, A. (2008) The ideation gap:: hybrid tools, design flow and practice. *Design Studies*, 29(2), pp. 121-141.
- DREYFUS, H.L. and DREYFUS, S.E. (1986) *Mind over Machine: the power of human intyition and expertise in the age of the computer.* Oxford: Basil Blackwell.
- ENGESTRÖM, Y., MIETTINEN, R. and PUNAMAKI, R. (1999) *Perspectives on activity theory.* 1st edn. Cambridge: Cambridge University Press.
- ERLHOFF, M. and MARSHALL, T. (2008) *Design Dictonary.* Basel. Birkhäuser.
- EVANS, M. (2002) *THE INTEGRATION OF RAPID PROTOTYPING WITHIN INDUSTRIAL DESIGN PRACTICE.* PhD Thesis edn. Loughborough University: Loughborough University.
- EVANS, M., WALLACE, D., CHESHIRE, D. and SENER, B. (2004) An evaluation of haptic feedback modelling during industrial design practice . *Design Studies*, 26(5), pp. 487-508.
- FABER, H. (2009) Digital Drawing Tablet to Traditional Drawing on Paper: A teaching Studio Comparison, *Rigor and Relevance: IASDR09*, 18-22 October 2009. Korean Society of Design Science.

- FISH, J. (2004) Cognitive Catalysis: Sketches for a Time-lagged Brain. In: G. GOLDSCHMIDT and W. PORTER, eds, *Design Representation*. London: Springer, pp. 151-184.
- FJELD, M.E.A. (2002) Physical and Virtual Tools: Activity Theory Applied to the Design of Groupware. *Computer Supported Cooperative Work*, 11, pp. 153-180.
- FORTY, A. (1986) *Objects of Desire: Design and Society Since 1750*. London: Thames & Hudson.
- GALLE, P. (2002) Philosophy of design: an editorial introduction. *Design Studies*, 23(3), pp. 211-218.
- GOEL, V. (1995) *Sketches of Thought*. London: The MIT Press.
- GOLDSCHMIDT, G. (2004) Design Representation: Private Process, Public Image. In: G. GOLDSCHMIDT and W. PORTER, eds, *Design Representation*. London: Springer, pp. 203-217.
- GOLDSCHMIDT, G. and PORTER, W., eds (2004) *Design Representation*. London: Springer-Verlag London Ltd.
- GOLDSCHMIDT, G. (1997) Capturing indeterminism: representation in the design problem space. *Design Studies*, 18(4), pp. 441-455.
- GOLDSCHMIDT, G. (1994) On visual design thinking: the vis kids of architecture. *Design Studies*, 15(2), pp. 158-174.
- GOLDSCHMIDT, G. (1992) Serial sketching: visual problem solving in designing. *Cybernetics and Systems*, 23, pp. 191-219.
- GOLDSCHMIDT, G. and SMOLKOV, M. (2006) Variances in the impact of visual stimuli on design problem solving performance. *Design Studies*, 27(5), pp. 549-569.
- GREEN, G. and Smrcek. (2005) The Application of Physical Models in Engineering Design Education. *Crossing Design Boundaries*. London: Taylor & Francis, pp. 323-331.
- GUIDOT, R. (2006) *Industrial Design Techniques and Materials*. English Language edn. Paris: Flammarion.

GÜNTHER, J. and EHRENSPIEL, K. (1999) Comparing designers from practice and designers with systematic design education. *design Studies*, 20(5), pp. 439-451.

HALLER, L. and CULLEN, C (2004) *Design Secrets: Products 2: 50 Real-life Projects Uncovered*. Mass: Rockport.

HEIDEGGER, M. (1962) *Being and Time*. 1st English edn. Translated from 7th German edn. Basil Blackwell.

HESKETT, J. (2002) *Toothpicks & Logos: Design in Everyday Life*. Oxford: Oxford University Press.

HESKETT, J. (1980) *Industrial Design*. London: Thames & Hudson.

HORNECKER, E. (2007) Drawings, Diagrams, Physical Models, Prototypes, and Gesture as Representational Forms, *Proceedings of the second Workshop on Physicality*, 2-3 September 2007, Lancaster university, UK.

HUANG, J., MA, M. and CHEN, C. (2007) Research on predicting models of annoyance under the operation of digital hi-tech products. *Design Studies*, 28(1), pp. 39-58.

HUDSON, J. (2008) *Process: 50 product designs from concept to manufacture* 1st edn. London: Laurence King.

JIANG, H. and YEN, C. (2009) Protocol analysis in design research: a review, *Relevance and rigour: IASDR09*, 18-22 Oct 2009, Korea Society of Design Science.

JONSON, B. (2005) Design ideation: the conceptual sketch in the digital age. *Design Studies*, 26(6).

JONES, C. (1981) *Design Methods: seeds of human design*. 2nd edn. Chichester: Wiley.

JONES, J.C. (1998) PhD Research in Design. *Design Studies*, 19(5), pp. 5-7.

JONSON, B. (2002) Sketching Now. *The international journal of Art and Design Education*, 21(3), pp. 246-253.

- JONSON, B. (2005) Design ideation: the conceptual sketch in the digital age. *Design Studies*, 26(6), pp. 613-624.
- JULIER, G. (2000) *The Culture of Design*. London: Sage.
- KOZULIN, A. (2003) *Vygotsky's educational theory in cultural context* 1st edn. Cambridge, Mass: Cambridge University Press.
- KUUTTI, K. (2001) Activity Theory as a potential Framework for Human-computer Interaction Research. In: B. NARDI, ed, *Contexts and Consciousness: activity theory and human-computer interaction*. 3rd edn. Cambridge, Mass: MIT Press, pp. 17-44.
- LAM, P et al. (2005) Contributions of designers to improving buildability and constructability. *Design Studies*. 27(4). pp457-479
- LAWSON, B. (2004) *What Designers Know*. Oxford: Architectural Press.
- LAWSON, B. (2006) *How designers think: the design. process demystified*. 4th edn. Oxford: Oxford University Press.
- LAWSON, B. and DORST, K. (2009) *Design Expertise*. oxford: Architectural Press.
- LOCKTON, D., HARRISON, D. and STANTON, N. (2010) The design with intent method: A design tool for influencing user behaviour. *Applied Ergonomics*, 41(3), pp. 382-392.
- LUCIE-SMITH, E. (1983) *A history of Industrial Design*. Oxford: Phaidon Press.
- MANOLYA, K et al (1998) Structure in Idea Sketching Behaviour. *Design Studies*, 19(4). pp485-517.
- MCCULLOUGH, M. (1997) *Abstracting Craft: The practiced digital hand*. London: MIT Press.
- MCGOWN, A., GREEN, G. and RODGERS, P.A. (1998) Visible ideas: information patterns of conceptual sketch activity. *Design Studies*, 19(4), pp. 431-453.
- MELLES, G (2009) Global perspectives on structured research training in doctorates of design – what do we value? *Design Studies*. 30(3). pp255-271

- MENEZES, A. and LAWSON, B. (2006) How designers perceive sketches. *Design Studies*, 27(5), pp. 571-585.
- MERLEAU-PONTY, M. (1962) *Phenomenology of Perception*. English 1st edn. Oxford: Routledge.
- MICKLETHWAITE, P. (2002) *What is design? : an empirical investigation into conceptions of design in the community of design stakeholders*. PhD. University of Huddersfield: University of Huddersfield.
- MIRANDA A. G. PEETERS, HARRIE F. J. M. (2007) The development of a design behaviour questionnaire for multidisciplinary teams. *Design Studies*, 28, pp. 623-643.
- MORRIS, J., 2008. *id software 2008*. Washington: Western Washington University.
- NARDI, B. (2001) Activity Theory and human-Computer Interaction. In: B. NARDI, ed, *Contexts and Consciousness: activity theory and human-computer interaction*. 3rd edn. Cambridge, Mass: MIT Press, pp. 7-16.
- NELSON, G. and STOLTERMAN, E. (2003) *The Design Way: Intentional change in an unpredictable world*. 1 edn. New Jersey: Educational Technology Publications.
- NOBLET, J. (1993) *Industrial design: reflection of a Century*. 1st edn. Paris: Paris: Flammarion.
- NORMAN, D. (2002) *The Design of Everyday Things*. 2nd edn. London: Thames & Hudson.
- OLOFSSON, E. and SJOLEN, K. (2006) *Design Sketching*. 2ed edn. Sundsvall, Sweden: Keeos Design Books AB.
- OXFORD UNIVERSITY PRESS (2006) *Oxford English Dictionary*. 11 edn. Oxford: OUP Oxford.
- PAN, R., KUO, S.-. and STROBEL, J. (2010) Novice students' difficulties and remedies with the conceptualization phase of design, *ASEE Annual Conference and Exposition*, 2010, ASEE.

- PEDGLEY, O. (2007) Capturing and analysing own design activity. *Design Studies*, 28(5), pp. 463-483.
- PEI, E (2009) *Building a common Language of design Representation for Industrial Designers & Engineering Designers*. PhD Thesis edn. Loughborough University: Department of design and technology. Loughborough University. UK.
- PEI, E. Campbell, R and Evans, M (2008) Building a Common Ground: The Use of Design Representation Cards for Enhancing Collaboration between Industrial Designers and Engineering Designers, *Undisciplined*, 16 - 19 July 2008 2008, Design Resaerch Society, pp. 037/1-037/18.
- PIPES, A. (2007) *Drawing for Designers*. London: Laurance King Publishing.
- PIPES, A. (1990) *Drawing for 3-Dimensional Design*. London: Thames & Hudson.
- PIROVANO, C. (1990) *History of industrial design. 1851-1918, The great emporium of the world*. Milan: Electa.
- POTTER, N. (2002) *What is a Designer: things.places.messages*. 4th edn. London: Hyphen Press.
- POWELL, D. (1985) *Presentation techniques*. London: Macdonald & Co.
- PRESS, M. and COOPER, R. (2003) *The design Experience*. London: Ashgate.
- PUGH, S. (1990) *Total Design*. Harlow: Addison-Wesley.
- PURCELL, T. and GERO, J. (1999) Design and other types of fixation. *Design Studies*, 17(4), pp. 363-383.
- PURCELL, A.T. and GERO, J.S. (1998) Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies*, 19(4), pp. 389-430.
- PYE, D. (2000) *The Nature and Aesthetic of design*. New edition edn. London: A & C Black Publishers Ltd.
- RAIZMAN, D. (2003) *History of modern design*. 1 edn. London: Laurence King.

- ROBERTSON, B.F. and RADCLIFFE, D.F (2009), Impact of CAD tools on creative problem solving in engineering design. *Computer-Aided Design*, In Press, Corrected Proof.
- ROBSON, C. (1993) *Real World Research*. first edn. Oxford: Blackwell Ltd.
- RODGERS, P., GREEN, G. and MCGOWN, A. (2000) Using concept sketches to track design progress. *Design Studies*, 21(5), pp. 451.
- RÖMER, A., PACHE, M. et al. (2001) Effort-saving product representations in design—results of a questionnaire survey. *Design Studies*, 22(6), pp. 473-491.
- SASS, L. and OXMAN, R (2006) Materializing design: the implications of rapid prototyping in digital design. *Design Studies*, 27(3), pp. 325-355.
- SCHON, D. (1983) *The Reflective Practitioner*. London: Ashgate.
- SIMON, H.A. (1996) *Science of the Artificial*. 3rd edn. London: MIT Press.
- SLACK, L. (2006) *What is Product Design?* Mies, Switzerland: RotoVision.
- STELLA, T. and MELLES, G. (2010) An activity theory focused case study of graphic designers' tool-mediated activities during the conceptual design phase. *Design Studies*, 31(5), pp. 462-478.
- STOLTERMAN, E. McAtee, J. Royer, D. Thandapani, S. (2008) Designerly Tools, *Proceedings of DRS2008, Design Research Society Biennial Conference, Sheffield, UK*, 16-19 July 2008, Sheffield University.
- SUWA, M. and TVERSKY, B. (1997) What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies*, 18(4), pp. 385-403.
- TOVEY, M. (1997) Styling and design: intuition and analysis in industrial design. *Design Studies*, 18(1), pp. 5-31.
- TOVEY, M., PORTER, S. and NEWMAN, R. (2003) Sketching, concept development and automotive design. *Design Studies*, 24(2), pp. 135-153.
- TOVEY, M. and OWEN, J. (2000) Sketching and direct CAD modelling in automotive design. *Design Studies*, 21(6), pp. 569-588.

ULLMER, B. and ISHII, H. (2001) Emerging Frameworks for Tangible User Interfaces. In: J. CARROLL, ed, *Human-Computer Interaction in the New Millenium*. Addison Wesley, pp. 579-601.

ULRICH, K. and EPPINGER, E. (2003) *Product Design and Development*. International Edn. New York. McGraw-Hill Education.

ULUSOY, Z. (1999) To design versus to understand design: the role of graphic representations and verbal expressions. *Design Studies*, 20(2), pp. 123-130.

Van Doren, H (1940) *Industrial design*. McGraw Hill, New York.

VAN HINTE, E. (1992) The secret of the design machine. *Industrieel Ontwerpen*, 8(4), pp. 1-2.

VELASQUEZ-POSADA, A. (2005) Model Making Techniques as a Teaching Tool in Product Design Engineering. In: P. RODGERS, L. BRODHURST and D. HEPBURN, eds, *Crossing DesignBoudaries*. 1 edn. London: Taylor & Frabcis, pp. 345-350.

VISSER, W. (2006) *The Cognitive Artifacts of Designing*. New York: Routledge.

WALKER, D. (1989) Managing Design: Overview. *Design Issues*, , pp. 791.

YOUNG, R, MACLARTY, E. and MCKELVEY, K. (2009) The Design Postgraduate Journeyman: Mapping the relationship between Design Thinking and Doing with Skills Acquisition for Skilful Practice, *IASDR09 Design Rigor & Relevance*, 18-22/10/2009 2009, KAIST.

Publications

Self ,J Dalke, H & Evans, M (2012) Design Tools and the Industrial Design Practitioner: An exploration of relationships between design tool, designer and the dynamic contexts of tool use. In Proceedings of DRS 2012 Bangkok. Bangkok, Thailand.

Self ,J Dalke, H & Evans, M (2011) Innovation in Knowledge Exchange: An approach to the dissemination of research findings in support of design practice. Submitted to special issue of 'Art, Design and Communication in Higher Communication' (ADCHE) at time of this report.

Self ,J Dalke, H & Evans, M (2011) Innovation in Knowledge Exchange: An approach to the dissemination of research findings in support of design practice. In Proceedings of Eksig2011 Skin Deep: Experiential knowledge and multi sensory communication. University of the Arts, Farnham, UK.

Self, J (2010) Reflections on the Designer's Sketch. KIOSK Magazine. Issue 04. Kingston University Press. Isbn 978-0-9557365-3-7

Self ,J Dalke, H & Evans, M (2010) The Sharpest Tool in the Box: An investigation of complex relationships between the industrial designer, design tools and design practice. In Proceedings of DesRes 2010. Loughborough University. Loughborough. UK

Self ,J Dalke, H & Evans, M (2009) Industrial Design Tools and Design Practice: An approach for understanding relationships between design tools and practice. In Proceeding of IASDR09 Design Rigor and Relevance. Seoul. South Korea. Isbn: 978-89-963194-0-5

Self ,J Dalke, H & Evans, M (2009) The Character of Design Tools: A Framework for Describing the Character of Design Tools and Their Relationship to Industrial Design Practice. In Proceeding of IASDR09 Design Rigor and Relevance. Seoul. South Korea. Isbn: 978-89-963194-0-5

Self. J, Dalke. H & Evans, M (2008) The In-This-World Digital Design Tool and Its Influence upon Reflective Practice. RX Futures Conference Series 08. Reading University Graduate School. Reading. UK

Appendix A
Surveys of Design Practitioners: Transformations

Industrial Design Tools II: Transformation

www.industrialdesignresearch.com



Kingston University London

Design Research Centre

Design Tools

What influences your preference for design tools?

We are looking at practitioner use of design tools: sketching, model making, RP, 3D CAD for the embodiment and communication of design ideas. From this we hope to gain insight into their affordances and constraints and by doing, help design students become more aware of the ways different design tools are used to support practice.

This questionnaire asks for your opinion on the characteristics of the design tools you use to construct design representations and embody your design ideas.

All information will be maintained in a strictly confidential manner in keeping with Kingston University's ethics guidance and procedures.

If you would like a summary of results or have any questions or comments I would be happy to answer them: K0729860@kingston.ac.uk

The questionnaire should take no more than 3-5minutes. Thank you for your generous assistance and time.

Design Research Centre, Kingston University London.

[Next](#)



Page 1 Details

Page 1 of 3

1. How would you describe the size of the company/consultancy you work in?

--Please Select--

2. What is your highest qualification?

--Please Select--

3. How would you describe the design discipline in which you work? Please choose the one closest answer:

--Please Select--

4. For how long have you worked in the above profession?

--Please Select--

Next



5. Do you use any of the following design tools during your design work? *Please check all that apply.*

- 1. 2D CAD technical drawing tools (to create GA etc)
- 2. Rapid prototyping tools (to produce SLA/SLS prototypes for example)
- 3. Conventional model making tools (to build wood/clay/plastic models)
- 4. Digital graphics tools (Adobe Illustrator for example)
- 5. Conventional graphics tools (marker rendering for example)
- 6. 3D digital modelling tools (3D Studio Max, Solidworks...)
- 7. Conventional Sketching tools (to create sketches)
- 8. Digital Sketching tools (Wacon Cintiq tablet for example)
- 9. Conventional sketch modelling tools (to build sketch models using foam/card etc)
- 10. 3D Printing (to produce models and prototypes)
- If other, please specify

6. The design tools listed below are most useful for: Work that moves from one design idea to a new design idea (lateral transformation).
Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD technical drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional model making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D digital modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. The design tools listed below are most useful for: Work on variations of one or the same design idea (vertical transformations).
Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD technical drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional model making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D digital modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[Previous](#) [Next](#)



Page 3 Any Thoughts?

Page 3 of 3

8. Is there anything you would like to add? Please use this space to add any suggestions, observations or criticism of the questionnaire, research, its aims and objectives:

4000

9. Would like to be sent a summary of the results? If so, please enter your email address below.

[Previous](#) [Submit](#)

Appendix B
Surveys of Design Practitioners: Embodiment

Design Tools II: Embodiment

www.industrialdesignresearch.com



Kingston University London
Design Research Centre

Design Tools

What influences your preference for design tools?

We are looking at practitioner use of design tools: sketching, model making, RP, 3D CAD for the embodiment and communication of design ideas. From this we hope to gain insight into their affordances and constraints and by doing, help design students become more aware of the ways different design tools are used to support practice.

This questionnaire asks for your opinion on the characteristics of the design tools you use to construct design representations and embody your design ideas.

All information will be maintained in a strictly confidential manner in keeping with Kingston University's ethics guidance and procedures.

If you would like a summary of results or have any questions or comments I would be happy to answer them: K0729860@kingston.ac.uk

The questionnaire should take no more than 3-5minutes. Thank you for your generous assistance and time.

Design Research Centre, Kingston University London.


[Next](#)

This survey is powered by www.surveymethods.com

Design Tools II: Embodiment

www.industrialdesignresearch.com

Kingston University London
Design Research Centre



Page 1 Details **Page 1 of 3**

1. How would you describe the size of the company/consultancy you work in?

2. What is your highest qualification?

3. How would you describe the design discipline in which you work? Please choose the one closest answer.

4. For how long have you worked in the above profession?

[Next](#)

This survey is powered by www.surveymethods.com



5. Do you use any of the following design tools during your design work? *Please check all that apply.*

- 1. 2D CAD technical drawing tools (to create GA etc)
- 2. Rapid prototyping tools (to produce SLA/SLS prototypes for example)
- 3. Conventional model making tools (to build wood/clay/plastic models)
- 4. Digital graphics tools (Adobe Illustrator for example)
- 5. Conventional graphics tools (marker rendering for example)
- 6. 3D digital modelling tools (3D Studio Max, Solidworks...)
- 7. Conventional Sketching tools (to create sketches)
- 8. Digital Sketching tools (Wacon Cintiq tablet for example)
- 9. Conventional sketch modelling tools (to build sketch models using foam/card etc)
- 10. 3D Printing (to produce models and prototypes)
- If other, please specify

6. The design tools listed below are useful for: Representing the engineering detail of design ideas.
Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD technical drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional model making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D digital modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. The design tools listed below are useful for: Representing the artistic/creative form of design ideas.
Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD technical drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional model making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D digital modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>


8. The design tools listed below are useful for: Representing design ideas in a more constrained unambiguous way.
Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD technical drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional model making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D digital modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[Previous](#) [Next](#)

Design Tools II: Embodiment

www.industrialdesignresearch.com



Kingston University London
Design Research Centre

Page 3 Any Thoughts? **Page 3 of 3**

9. Is there anything you would like to add? Please use this space to add any suggestions, observations or criticism of the questionnaire, research, its aims and objectives:

4000

10. Would like to be sent a summary of results? If so, please enter your email address below.

[Previous](#) [Submit](#)

This survey is powered by www.surveymethods.com

Appendix C
Surveys of Design Practitioners: Communication

Industrial Design Tools II: Communication

www.industrialdesignresearch.com



Kingston University London

Design Research Centre

Design Tools

What influences your preference for design tools?

We are looking at practitioner use of design tools: sketching, model making, RP, 3D CAD for the embodiment and communication of design ideas. From this we hope to gain insight into their affordances and constraints and by doing, help design students become more aware of the ways different design tools are used to support practice.

This questionnaire asks for your opinion on the characteristics of the design tools you use to construct design representations and embody your design ideas.

All information will be maintained in a strictly confidential manner in keeping with Kingston University's ethics guidance and procedures.

If you would like a summary of results or have any questions or comments I would be happy to answer them: K0729860@kingston.ac.uk

The questionnaire should take no more than 3-5minutes. Thank you for your generous assistance and time.

Design Research Centre, Kingston University London.

[Next](#)

Industrial Design Tools II: Communication

www.industrialdesignresearch.com



Kingston University London

Design Research Centre

Page 1 Details

Page 1 of 3

1. How would you describe the size of the company/consultancy you work in?

--Please Select--

2. What is your highest qualification?

--Please Select--

3. How would you describe the design discipline in which you work? Please choose the one closest answer:

--Please Select--

4. For how long have you worked in the above profession?

--Please Select--

Next



Page 2 The Characteristics of Design Tools: Communication

Page 2 of 3

5. Do you use any of the following design tools during your design work? *Please check all that apply.*

- 1. 2D CAD technical drawing tools (to create GA etc)
- 2. Rapid prototyping tools (to produce SLA/SLS prototypes for example)
- 3. Conventional model making tools (to build wood/clay/plastic models)
- 4. Digital graphics tools (Adobe Illustrator for example)
- 5. Conventional graphics tools (marker rendering for example)
- 6. 3D digital modelling tools (3D Studio Max, Solidworks...)
- 7. Conventional Sketching tools (to create sketches)
- 8. Digital Sketching tools (Wacon Cintiq tablet for example)
- 9. Conventional sketch modelling tools (to build sketch models using foam/card etc)
- 10. 3D Printing (to produce models and prototypes)
- If other, please specify

6. The design tools below: Communicate a high level of commitment to design ideas.

Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD Technical Drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid Prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional Model Making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital Graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional Graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D Digital Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. The design tools below are more useful for: Communicating design intentions to others.

Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD Technical Drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid Prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional Model Making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital Graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional Graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D Digital Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

8. The design tools below are more useful for: Aiding self reflection and the dynamic generation and evolution of design ideas.

Do you agree or disagree?

	Strongly Agree	Mostly Agree	Neutral	Mostly Disagree	Strongly Disagree
1. 2D CAD Technical Drawing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. Rapid Prototyping	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. Conventional Model Making	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. Digital Graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. Conventional Graphics	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. 3D Digital Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. Conventional Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. Digital Sketching	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. Sketch Modelling	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. 3D Printing	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

[Previous](#) [Next](#)



Page 3 Any Thoughts?

Page 3 of 3

9. Is there anything you would like to add? Please use this space to add any suggestions, observations or criticism of the questionnaire, research, its aims and objectives:

4000

10. Would like to be sent a copy of the results? If so, please enter your email address below.

[Previous](#) [Submit](#)

Appendix D
Surveys of Design Students: Part I



Design Tool: SKETCHING

Q1. Please say to what extent you disagree or agree with the following 8 statements about your use of SKETCHING (If you don't use sketching please go to Q2). SKETCHING HELPS YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>4. Move easily from design one idea to another idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>

UTT 1 Sketching tools and representations

THINKING

Conventional Sketching representation

For example:

- Referential Sketch
- Shape Configuration Sketch
- Generation Focused Sketch

THINKING

Less structured concept design

UTT 1 Sketching tools and representations

Conventional Sketching tool

For example:

- Sketchbook and Pen
- Pencils and Drawing tools

Less structured concept design

Q2. Your education taught you to consider the outcome of a stage in practice and choose the tool to support that outcome:

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: Sketch Model Making

Q3. Please say to what extent you disagree or agree with the following 8 statements about your SKETCH MODEL MAKING (If you don't use sketch model making please go to Q4). SKETCH MODEL MAKING HELPS YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>4. Move easily from one design idea to another idea</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>

UTT 3 Conventional sketch modelling tools and representations

Sketch Model Making Tools

For example:

Foam/Clay Shaping Tools
Material Reduction Hand Tools

Less structured concept design

UTT 3 Conventional sketch modelling tools and representations

Sketch Model Making Representation

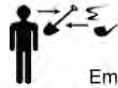
For example:

Sketch Model
Experiment Model

Less structured concept design

Q4. Your education taught you to choose the design tool you feel most comfortable with and then consider how to use it to best support your work:

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: NON-DIGITAL GRAPHICS TOOLS

Q5. Please say to what extent you disagree or agree with the following 8 statements about your use of NON-DIGITAL GRAPHICS TOOLS (If you don't use non-digital graphics tools please go to Q6). NON-DIGITAL GRAPHICS TOOLS HELP YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>4. Move easily from one design idea to another idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>

um6 Conventional Graphics tools and representations

16

Conventional Graphic Tool

For example:

- Markers and pencil
- Tape drawing/ airbrush work

Semi-structured development design

um6 Conventional Graphics tools and representations

Conventional Graphic Representation

For example:

- Story/Theme board illustrations
- Marker Rendering

Semi-structured development design

Q6. Your education made clear the relationship between the characteristics of design tools and how these characteristics support design practice:

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: CONVENTIONAL MODEL MAKING

Q7. Please say to what extent you disagree or agree with the following 8 statements about your use of CONVENTIONAL MODEL MAKING (If you don't use conventional model making please go to Q8). CONVENTIONAL MODEL MAKING HELPS YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>	<p>5. Focus on variations of the same design idea</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>
<p>2. Represent the artistic/creative form of design ideas</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>	<p>6. Communicate a high level of commitment to design ideas</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>
<p>3. Represent design ideas in an unambiguous way</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>	<p>7. Clearly communicate design intention to others</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>
<p>4. Move easily from one design idea to another idea</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p> <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> — <input type="checkbox"/> Agree Strongly Agree Undecided Disagree Disagree Strongly </p>

UTT8 Conv Model Making tools and representations

Model Making Tools

For example:

Wood/Plastic Machining
Material reduction and shaping tools/processes

Structured detail design

UTT8 Conv Model Making tools and representations

Model Representations

For example:

Semi-Functional Model
Pre-production Appearance Model

Structured detail design

Q8. Your education provided a good knowledge of the use of design tools and you do not require any more information:

— — — —
 Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: 2D CAD DRAWING TOOLS

Q9. Please say to what extent you disagree or agree with the following 8 statements about your use of 2D CAD DRAWING TOOLS (If you don't use CAD drawing tools please leave blank). 2D CAD DRAWING TOOLS HELP YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>5. Focus on variations of the same design idea</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>2. Represent the artistic/creative form of design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>6. Communicate a high level of commitment to design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>3. Represent design ideas in an unambiguous way</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>7. Clearly communicate design intention to others</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>4. Move easily from one design idea to another idea</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>

UNIT 10 2D CAD tools and representations

CAD Tool

For example:

- Autodesk AutoCAD
- Autodesk Inventor
- Siemens PLM NX CAD

Structured detail design

UNIT 10 2D CAD tools and representations

CAD Representation

For example:

- GA Drawing
- Plan/Sectional Drawing
- Technical Detail Drawing
- Technical Detail Illustration
- Perspective Illustration

Structured detail design

Thank you for your time!

Appendix E
Surveys of Design Students: Part II



Design Tool: DIGITAL SKETCHING TOOLS

Q1. Please say to what extent you disagree or agree with the following 8 statements about your use of DIGITAL SKETCHING TOOLS (If you don't use digital sketching tools please go to Q2). DIGITAL SKETCHING TOOLS HELP YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>4. Move easily from one design idea to another idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>

um2 Digital Sketching tools and representations

Digital Sketching tool

For example:

- Wacom Cintiq Graphics tablets
- AutoDesk SketchBook Pro
- PTC Pro/Concept

Less structured concept design

um2 Digital Sketching tools and representations

Digital Sketching representation

For example:

- Referential Sketch
- Shape Configuration Sketch
- Generation Focused Sketch

Less structured concept design

Q2. Your education taught you to consider the outcome of a stage in practice and choose the tool to support that outcome:

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: 3D PRINTING

Q3. Please say to what extent you disagree or agree with the following 8 statements about your use of 3D PRINTING (If you don't use 3D printing please go to Q4). 3D PRINTING HELPS YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>4. Move easily from one design idea to another idea</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p>□ — □ — □ — □ — □</p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>

ut4 Digital 3D Printing tools and representations

Digital 3D Printing Tool

For example:

3D Systems 3D Printers
Z Corp 3D Printers

Less structured concept design

ut4 Digital 3D Printing tools and representations

Digital 3D Printing Representation

For example:

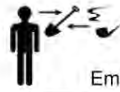
Concept Model
Experiment Model

Less structured concept design

Q4. Your education taught you to choose the design tool you feel most comfortable with and then consider how to use it to best support your work:

□ — □ — □ — □ — □

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: DIGITAL GRAPHICS TOOLS

Q5. Please say to what extent you disagree or agree with the following 8 statements about your use of DIGITAL GRAPHICS TOOLS (If you don't use digital graphics tools go to Q6). DIGITAL GRAPHICS TOOLS HELP YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>
<p>4. Move easily from one design idea to another idea</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p><input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Agree Strongly Agree Undecided Disagree Disagree Strongly</p>

um5 Digital Graphics tools and representations

Digital Graphics Tool

For example:

- Adobe Illustrator/Photoshop
- Autodesk AliasStudio

Semi structured development design

um5 Digital Graphics tools and representations

Digital Graphic Representation

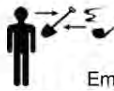
For example:

- Sketch/Digital Hybrids
- Generated Visuals

Semi structured development design

Q6. Your education made clear the relationship between the characteristics of design tools and how these characteristics support practice:

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: 3D DIGITAL MODELLING TOOLS

Q7. Please say to what extent you disagree or agree with the following 8 statements about your use of 3D DIGITAL MODELLING TOOLS (If you don't use 3D digital modelling please go to Q8). 3D DIGITAL MODELLING TOOLS HELP YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>5. Focus on variations of the same design idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>2. Represent the artistic/creative form of design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>6. Communicate a high level of commitment to design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>3. Represent design ideas in an unambiguous way</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>7. Clearly communicate design intention to others</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>
<p>4. Move easily from one design idea to another idea</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p><input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly</p>

Unit 7 Digital Modelling tools and representations

Digital Modelling Tools

For example:

- Autodesk Maya/3ds Max des
- Rhinoceros Nurbs modeller
- Solidworks Premium
- Solidthinking

Semi-structured development design

Unit 7 Digital Modelling tools and representations

Digital Modelling Representation

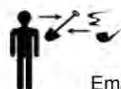
For example:

- Design development Models
- Presentation Models

Semi-structured development design

Q8. Your education provided a good knowledge of the use of design tools and you do not require any more information about them:

Agree Strongly Agree Undecided Disagree Disagree Strongly



Design Tool: RAPID PROTOTYPING

Q9. Please say to what extent you disagree or agree with the following 8 statements about your use of RAPID PROTOTYPING (If you don't use RP please leave blank). RAPID PROTOTYPING HELPS YOU TO:

<p>1. Represent the engineering detail of design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>5. Focus on variations of the same design idea</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>2. Represent the artistic/creative form of design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>6. Communicate a high level of commitment to design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>3. Represent design ideas in an unambiguous way</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>7. Clearly communicate design intention to others</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>
<p>4. Move easily from one design idea to another idea</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>	<p>8. Reflect upon and quickly generate new design ideas</p> <p> <input type="checkbox"/> Agree Strongly <input type="checkbox"/> Agree <input type="checkbox"/> Undecided <input type="checkbox"/> Disagree <input type="checkbox"/> Disagree Strongly </p>

um9 RP tools and representations




RP Tool

For example:

- 3D Systems SLA/SLS RP
- AutoDesk Digital Prototyping
- PCT CoCreate Modeling

Structured detail design

um9 RP tools and representations



RP Representation

For example:

- Tooling Prototype
- Pre-Production Prototype
- Functional Prototype

Structured detail design

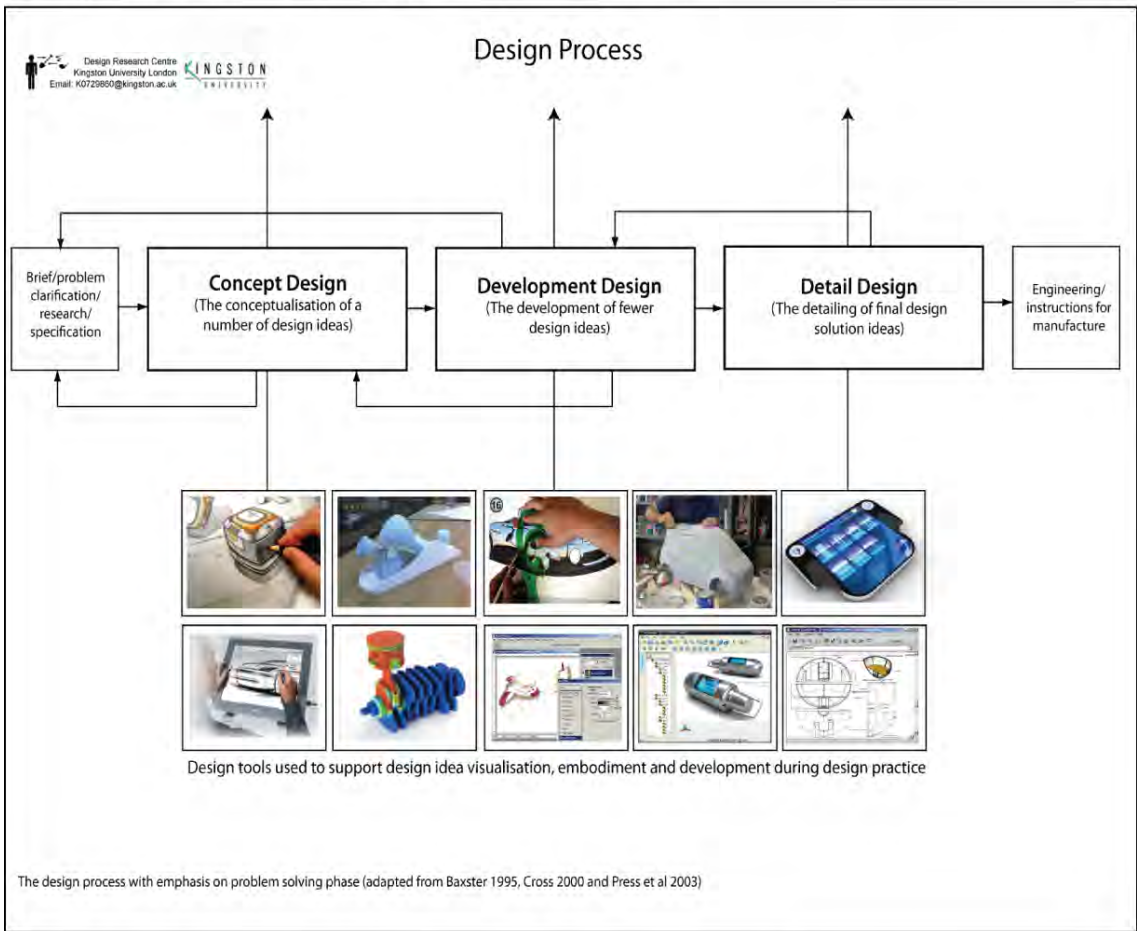
Thank you for your time!

Appendix F
Practitioner Interview Guide

Design Tool use by Industrial Designers

This questionnaire is part of a research programme examining the use of design tools during practice. By 'design tool' we mean the various media and processes through which industrial designers embody and communicate their ideas - Sketching, CAD or RP for example

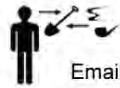
1. Many design academics have used a three stage model to describe the 'problem solving' phase of ID practice. What do you think of this model in terms of your own practice experience?



Survey No:

Date

Time:

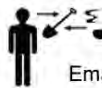


4. What tool(s) do you use most during your conceptual design work?

5. Could you suggest reasons why [XXX] tool(s) are used most during your conceptual design work?

6. What tool(s) do you use the most during your development design work?

7. Could you suggest reasons why [XXX] tool(s) are used most during your development design work?



8. What tool(s) do you use most during your detail design work?

9. Could you suggest reasons why [XXX] tool(s) are used most during your detail design work?

10. In terms of visualisation and modelling abilities, what do you look for in a graduate designer's portfolio when considering them for employment in your organisation?

11. Given the abilities you've suggested, could you say why it is important for a designer to have these specific skills?

Thank you*

Appendix G
Interview Transcripts with Annotation

Practitioner Interview: Pr01

Practitioner Interview	Pr01
Date/Time	Mon 15 th July 2009. 16:00 -16:45
Consultancy	XXXXXX Design Ltd
Interviewee	XXX XXXX (CL)
Position	Managing Director
Interviewer	James Self (JS)

JS: I presume you've been in industrial design a number of years?

CL: So, right from my point of view, from what you've been saying, my background is, yes. I did an industrial design course up in Newcastle. So that time would have been 84 to 88 and the only computers you had there were actually for typing out documents. There was defiantly no modelling software at all. So, to me, it was sketching and model making, so we would form in foam, plastic etc. The first time a really got introduced to computer modelling was when I worked for a company, for I.A.D; International Automotive design. And they were, at the time, one of the biggest car consultancies in Europe. They obviously got some European funding. Now, on the engineering side, for the likes of Katea, and things like that, they had, you know, a development side of things where they were doing CAD drawings but they were also creating, if you like, digital models. And, through this Government, European fee, that was sort of like a grant for, what turned out to be Alias. I guess it's now AutoDesk Alias 2 but at the time it was Alias. And this machine came in and it looked the size of a fridge. Every body played the aeroplane landing game on it in the science studio.¹⁴

And that was it, it sat there and one day I looked at it and thought, it's also meant to do something more than this. And that it had this modelling package that was meant to be for designers. So that was in about 19...91ish something about there. At which point I got a bit of training on it and, that really was it. I did a project, down there, that was a speaker for BMW speakers. And that was the first time that that company had done anything on the computer in a design styling sense, and, I think, up to then it had been foam models, clay. At that time, from a designer's point of view, it certainly didn't do what it said it could do. You couldn't do great surfaces, from a design point of view. It wasn't intuitive etc.¹⁵

And, where you are now, Drive, I left I.A.D, I went to another company, which was, basically based on the fact that the software and digital modelling was going to be the future of design. It was going to play a massive part. And so Drive, if you like, is based on the back of that. Where we see the importance of the digital modelling.¹⁶

Now, that comes to me employing people here. The first thing I want to see is there sketch pad. I want to see how well they can sketch because, they're going to be working with designers or they're going to be designing themselves. And I want to see that when they sketch, they can understand form. So if that just means a section lined through the side of the body of the car, it means on that product [pointing to picture of 'razor' on wall], they're describing that shape to me.¹⁷

And I want them to know what happens on the other side of that sketch. So it they've drawn it from, from three quarter view, I want to know that when they're sketching the back view they know where the lines are meeting up and how the form is. So I think, I think like you're saying, that, that, colleges, I think they should sketch, they should defiantly physically model, weather that be in foam or in clay. And that should be, certainly, the early requirement of their course work. Because that's when their understanding form,

¹⁴ 02CL_Intro_TOOL CAD

¹⁵ 02CL_Intro_TOOL CAD

¹⁶ 02CL_Intro

¹⁷ 02CL_TOOLSketch

where they'll understand to construct something. My worry about the computer side of things. Two things, when you sketch and do a really good rendering by hand, yes, they're using Photoshop now because that is an advantage on the old pastel and the old marker pen. But even that loses some of the emotion. And as soon as they go to computer model, all emotion of the design is lost. It is cold. It is hard. It's, it's there.¹⁸

JS: Could you say a little more about your idea of emotional loss, through the computer. Yes, others have criticised the use of computer modelling but there must be reasons for that. I'm just wondering why you see CAD representation as less emotional or lacking creativity, cold, hard?

CL: I think that's because it's so precise. I think what tends to, tends to happen, that the, I'm jumping around slightly, but from that point of view, from losing the emotion, some of it's, the student's problem is that they don't know how to model what they've designed on the computer. So their designs are actually influenced by that they can achieve on the computer. So...¹⁹

JS: So are you now talking about the interface? So the designs are limited to what can be achieved on the computer, a working through the tool there?

CL: Yes.

JS: And so there is the interface that is worked through and so that has implications for the way the designer is able to design?

CL: Yes, I think so. That worries me when I see people who have designed on the computer and then they do not show whether they actually have the experience to take the design to that stage. Or that is the limit of their ability. That is where I think a sketch is much more intuitive. That they can sketch a design and even taking a foam model and hacking into it and then adding something back on. Even now doing a good fillet on a computer model is difficult. Sometimes you wish you could get a lump of clay and just push it down use your thumb, get the fillet done. So there's something about that, sort of worries me. The computer side of the designer point of view. And then the emotion side of things, I think it is because it's so clean, so perfect. Where as a sketch you can let the lines flow past which gives a movement. But when you have a static 3D object that you spin round on a screen it does feel static. Even where you can blur the wheels isn't quite so easy to do just by the look of the image [on the computer]. And also the closer it looks to reality, the less your imagination can fill in the gaps.²⁰

JS: Do you find that then can cause problems in communication with clients. What I mean is, perhaps a concept idea is represented as a slick 3D CAD model; in a presentation to the client it almost seems too finished?

CL: You could look at it a flick on both sides. That initially, that I guess, there's gaps in sketches and that bit of shadow can mean something to a designer. From a client or the person designed it. So if they look at it they can read into it that, that shape's concave. Where actually the designer's thought it was convex; just a bit of shadow, a bit of highlight.

I think on the computer it removes some of that. It's, it's a definite shape. And the clients do get scared when they look at something and say, it's not what I was wanting. Or because it's quite, it's almost finished isn't it. They're thinking that's what they're going to get. They're not reading it as being actually. And equally the other down side is, showing them something like that and they think it is done. Therefore they're thinking that's great, let's go to tooling. Well actually, it can't look like that at the end of the day.²¹

JS: My research is looking at the idea that the sketching and the physicality of sketch modelling, for example, when your shaping with the foam, it maybe something to do with that. Even with a pen, perhaps when you're sketching, the way you can lean and feel what you're doing.

¹⁸ 02CL_TOOLSsketch CAD Comparison

¹⁹ 02CL_TOOLCAD

²⁰ CL02_Q_Introduction_Continued

²¹ 02CL_TOOLCAD

CL: I think there is a light. This is a touch. You know, you can be aggressive with the line, Heavy, you know you can bring that all in.

There's a sketch programme, and I don't know if it's a real one or not, um love sketch.com probably. And I think if you Utube it even. This is somebody who, or some people how have got together to, imagine that you sketch the line with dots so you do your first sketch. You do a little plane and it's a sketch. Then, once you've created the other sketch, so if it's a window line on a car or it's a screen on a phone that creates the surface between it. And that feels intuitive and it feels like a designer sketching. But as you sketch it's creating the model, the digital model. As apposed to he's sketched it. He's underlayed it. Then he's creating the lines. So, have a look for that one.²²

There also is another little programme to play around with called Concept Sketching.com. And that's not up yet but that's just more sketch programme to play around on.

JS: Are you familiar with the Haptic force-feedback device?

CL: Yes. We don't have it here. We looked at it. A lot of our work is more; I think a lot of people use it for more, is it shoe design? Doing the souls, carving away with it? I think Model Makers use it a lot. We haven't as yet, but within product design, I think maybe somebody put sunglasses on it or something at one point.²³

JS: I just wondered. There have been some negative responses to that system being useful for industrial design. Again, it seemed to be coming back to the fact that, yes, the designer can feel the digital geometry on the screen but they're feeling just a pens width. There's not that. If you're making a clay model, for example, a sketch model perhaps, there's a manipulation of the object 'in-hand'...

CL: It's like that, people just love to just run there hand down the side of a car, love to feel so, if they're looking at a digital model, it's, it's just remote. There is something tactile about objects that get missed.

JS: OK interesting. If I could just ask you, you have covered some of this in your response to other questions, but if I could just ask you specifically. If you, for example, you go to Young Designers' and you are interested in a graduate, a new graduate, what would be the skills set, the ideal skill set, with particular reference to their abilities and skills in the use of different tools, you look for. So, rapid prototyping, model making skills, sketching, 3D CAD?²⁴

CL: For me at the moment? OK, if I'm putting an out-and-out designer hat on, I would like to see their sketching first and foremost, a well resolved model, but that doesn't necessarily mean to me that they've done it all. Because if I go now and look at the Royal College of Art or I go to Coventry, I'm using car because it's what I can refer to straight away. Some people there have done there designing and they've gone and got Bentley to create their model. They've got Drive to do the digital modelling for them. So you look at a show and you're not sure just who's done what. But, those sorts of designers have had the foresight to have a design, so that if it's a good design that's great. If it's a bad design end of story. What's the point?

But they've had a good design. They've then program managed. So they've had to go see some people, quite early on to get in first because every man and his dog are trying to do it. They've then had to pull together; a lot of them don't have the nerve to do it, but to pull together the favours. Then, maybe they've had to get somebody to spray it up. So it's a program management, you know. They've done a complete job. But in reality, somebody's a designer, quite often if they're good that's what they're going to end up doing. They're going to end up sketching the design but they're not going to be the person, and this goes back to when it was clay models and foam models, they're not the person that's going to deliver that model, Their the creators. So, they're going to do the sketch. They're then going to bring it through. Give it to somebody else to develop on. And nowadays a lot of people fall into being, you know, CAD modellers, Alias modellers, forever. They're the people that want to be designers, don't feel they're quite

²² 02CL_CAD as Sketch TOOL

²³ 02CL_TOOLHaptics

²⁴ CL02_Q8/Q9 Skills Set

good enough, have found a skill in the Alias modelling or computer modelling and then have, almost, gone down that rout. They might be asked to go to be a designer that can use that system. But, I think still, at the moment, let's say, they're still going to be found to do more modelling, maybe from other peoples designs, then they are of their own.²⁵

I think that will change because soon everybody's going to use it. And I think they will need to use it a certain extent, but I would say they, they won't be the experts on how to get the best finished model. And just like they would on clay, they might drop out a bit and the guy says, oh what does it look like round there? So they carve out and say that's what we're thinking. Then get somebody else to polish it off. So there's almost room for a system that allows people to do a very quick model that doesn't have to have the technical tangency, curvature, perfect surface. Just needs something to give the volumes, give the overall appearance. A bit like, I guess, sketch rendering against a technical GA layout drawing. This would be something intuitive, something there that they could get out of it. But not want to be going back. And maybe that's where the learning is. They're told how to build like, exactly like creating a good curve, creating a good surface. But may be they should be being told to use a spear to pull all the point round to to get it to the shape you want. Forget all this technical bit. But it's, it is difficult because if they came into a professional job and said right, 'we're just going to pull this around' everybody would go, 'no that's not what we're looking for. We're looking for...?'²⁶

So I think we've gone off a tangent a bit. But if they can't design. If they can't express their design by sketching by good design. Then I think, I'm not saying it's just sketching, but the design has to come first. Then, you know, how you represent it obviously is important, but if the ideas aren't there, then you're not going to be able to give them that. You can teach them modelling, maybe on the computer, you can get somebody else to model it up for them, if they can't do it, but you can't teach them to be a good designer.²⁷

JS: So you're saying that your ability to judge a graduate as a good designer comes out more in their sketch work than in their CAD work?

CL: I think so because you can see their thought process. If, that's what I also like, original sketches. I know everyone likes a PowerPoint. I know everyone likes to turn up and it's great on the laptop. But they can Photoshop a sketch image to print the best sketches from twenty pages and put them on one sheet. And it looks very convincing. But what I'd like to see are the twenty sheets and see that, actually, there's a bit of rough sketching there, but it'll give an idea to their. If in the middle of a sketch he has moved onto his next idea because he's finished with that one. Where as, there's a tendency to present, 'Oh I'm going to really finish off this design, I really like. I'm going to do this sketch and then get onto the next one'. But if you see the rough sketches, you see that he has already worked out that that was done and dusted and he's put on some new machine, and again, as a designer, they've moved it on. So I like to see the original stuff.²⁸

The rest are tools. If it's a clay modelling tool. If it's Alias software. If it's, they're just tools to the end result. But the creative idea.

JS: So what you seem to be saying is, that their might be something about the sketch that allows you to work between ideas. If you are working on a CAD tool your design is more concentrated. Where as with a sketch you are able to sketch and move on?

CL: You can move very quickly through your ideas, certainly. And I think, and I think again, maybe even CAD model. If you've got a very good designer, who's come to sketch and he knows what he wants. The guys modelling on the computer will model that car. And they'll be really happy when he says, 'oh look can we change that bit by 2mm' because he knows where he's going. So he's seen it and he wants to move it. If they've got a designer who doesn't know what he wants, they can just go through loop and loop and loop and loop and loop. And they'll get really fed up changing it because he's looking for the

²⁵ 02CL_Q8/Q9 Skills Set

²⁶ 02CL_Q9 Skills Set and CAD

²⁷ CL02_Q8/Q9 Skills Set and Creativity

²⁸ 02CL_Q9 Skills set and Sketching

result. Well you might as well be sketching. You might as well resolve that a little bit. But, when they work with somebody who knows what they want it's, they'll change it all day long because they know they're going somewhere with it.²⁹

JS: How does that come? Is that down to experience the designer knows what they want or do you think that...

CL: I think the design part of it comes from that. I think the modelling part. Why our guys are so good on the modelling is that they've come from design, first and foremost. So we do understand design. They've not come from, 'I Connect' to you and I can use the computer system. How can I put this? Kintea and Isanser are 'A' class car design services. Production tool services. What those people's specialists are taking a model and making sure the surface is perfect. But they've already got the model there. Ask if they know whether their surface is right or wrong, because, you have hit that point and the flow lines are correct. If you were to say to them, right, 'work this design and create something from nothing' they wouldn't know where to start. So this creative aspect has to be there. Our modellers are good because they come from design. They can model up and they can work with the designer. And they also will, because they've got an eye, they can put in the light that they know is going to be right to save time. So a designer will come, dump sketch and say model that in. Well, they'll know that, through the modelling, that it's not looking right. So let's just tweak it closer to what we think will be right. Might not be bang-on but it's saved the designer coming back and saying, 'no that's not right'. So we've moved on slightly. So, through the model there're developing it. But, it's a two way thing. Once you've got a good designer and a good modeller, not a surface, but a modeller, working on it then they can really push that design forward.³⁰

JS: Ok interesting, thank you. Now, lastly, I'm going to show you a model of the design process that's based on models from design research (see fig.1). Could you have a look at this model and give me your reaction to it?

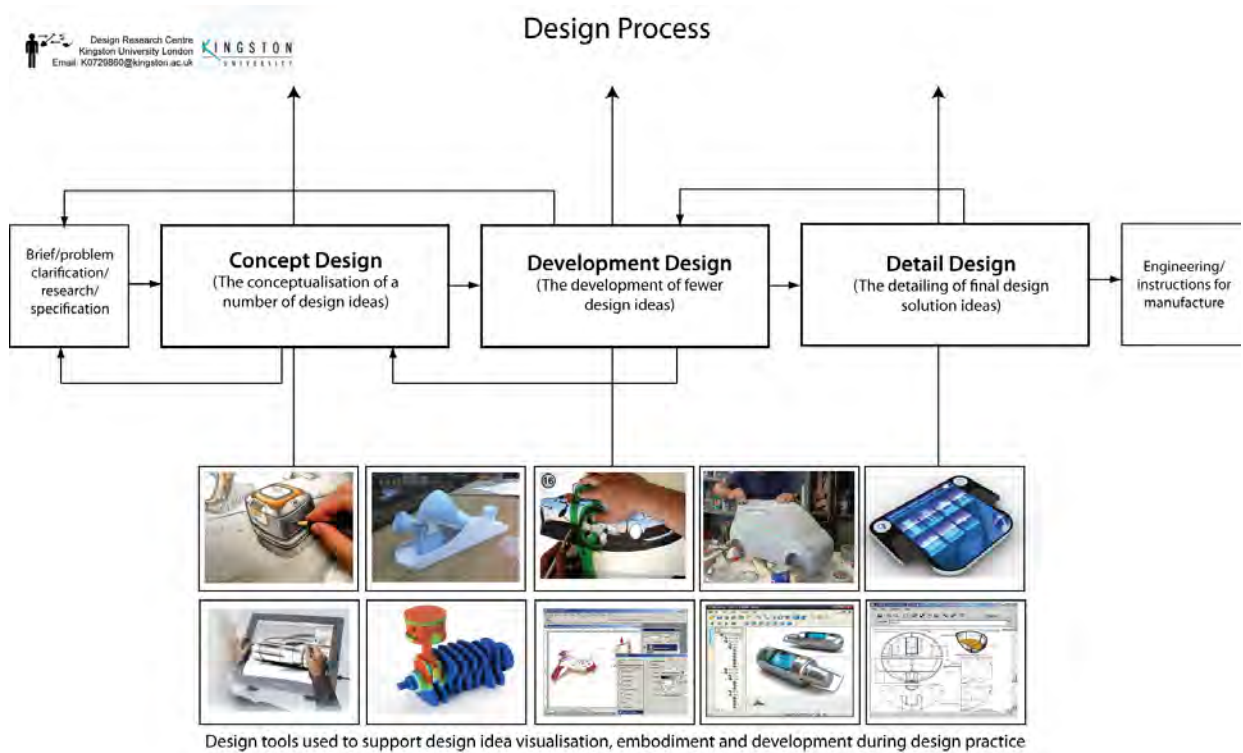


Figure 2: Stages model of design process based on Cross (?), Baxster (?) and Press et al (?). Shown to practitioner

²⁹ 02CL_TOOL Sketching

³⁰ 02CL_origion of creativity

CL: So we start from here...

JS: The model concentrates on this area of design practice [pointing to concept, development and detail design, fig 1]. Of course there is an area of problem identification, a brief and research. However, this model focuses on problem solving, where it moves and funnels from concept design to development and onto detail design. Then out towards manufacture.

CL: Yes. It's sort of, I think correct, in a sense. I believe, and I'll just do a very quick sketch. This still to me feels it's a traditional way, and I think it's probably correct, and to me it's like this, [starts to draw own sketch of design process on paper], fig 2.

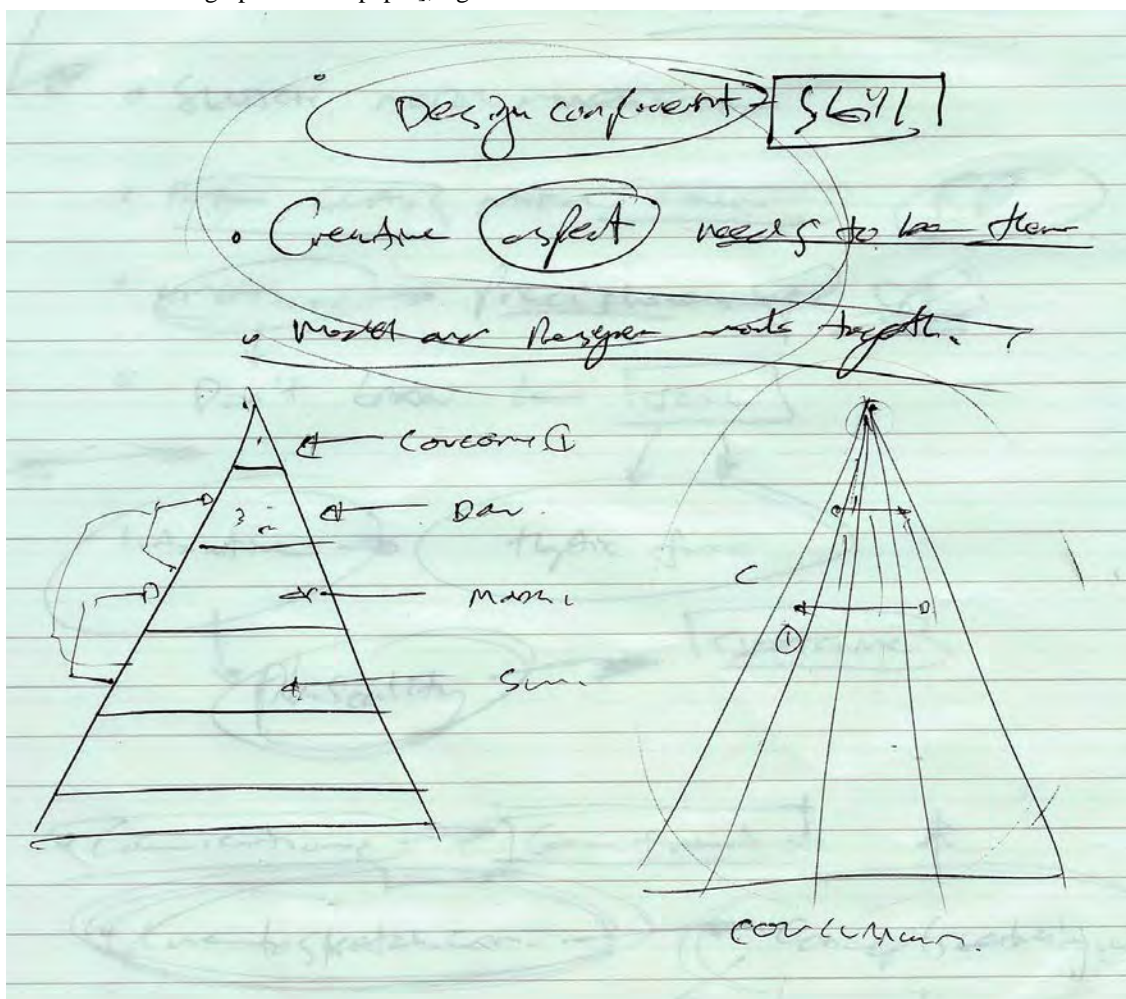


Figure 3: Sketch of design process by practitioner

And you're almost right. There is this concept stage [labels 'concept', 'Dev', 'Manuf' on own model of practice, fig 2], and you can imagine there's, you know a designer working. So it's almost one person [writes '1' at apex of triangle in own model of practice, fig 2]. Then modelling and you've got a few more people because you've got the modeller and the designer. And on this, sort of, and what you're saying is you just look back and you're sort of saying, ok where would it be so, [continues to sketch model of process] brief if you like, concept, concept development, a bit of model making, maybe. Err, then, proper surfacing. And like you've got here the loops coming back, you're almost doing this look back, [points to loop from development to concept design on original model of practice, fig 1]. That's got to go back to there. That's got to go back to there. It's really sort of linier. I would say that the process should be more like this, [writes number '2 and 3' at top of own triangular model of practice, fig 2]. Where you've got the designer, or concept, if you like. One concept, going through here, model making, [draws second triangular model of practice adjacent to first, adds 'c' for concept and '1' to indicate one designer/Design,

fig 2]. Digital, engineering [draws line horizontally across triangle to indicate location of digital engineering during practice, fig 2]. So that you're starting off with a small team of one of each. And as it grows, say on a mobile phone, you're have somebody working away on the shell. But you're need the user interface guy. Well to start with he might not be needed, till we see what's happened. Same with the model making. You just need one guy to rough something out, as it grows. So this whole range should be more like this and it's more a line going across, [again indicates lines running parallel across own triangular model of practice, fig 2] the information, works. So, this loop back, [adds arrowhead lines to indicate looping back on own model of practice, fig 2]. It is what happens, but in reality it shouldn't be this detail. Some of that should be happening up here [points to detail design stage in practice and example tools, fig 1, indicating that the tools used should also be used during development design]. So this is more... I think the process that should be getting used, to me it is, there's no reason why, something like this, [pointing to sketch modelling design representation on fig 1] that the very quick model, digital model or something, isn't being used at this stage so, a bit, a photograph of this sketched over, [points to same sketch model in original model of practice and indicates development design, fig 1] isn't part of development. So that's all at the same point as apposed to, some really nice visuals here that show the metals as. Well [indicating development design in original model of practice, fig 1] there's no reason why some of that couldn't be there [indicating detail design, fig 1]. Does that make sense?³¹

JS: Yes I think so?

CL: So that's just how, I sought of see it. So almost the concurrent, sort of process [indicating own model of practice, fig 2] this goes through. I mean this is right [referring back to original model, fig 1] pretty much most of the time this is what happens. But what you'll find is there's much more, of this involvement up here [indicates the tools used during detail design in original model of practice, fig 1]. I think. So, engineering for manufacture [indicates final stage in original model of practice, fig 1]. Well, that has to come up here somewhere [indicating detail design stage, fig 2]. So although this is research and specification [pointing to original model of practice, fig 1].³²

JS: To be built into concept [pointing to brief/research/specification on original model of practice, fig 1] it's all more fluid, slightly more mixed and involves?

CL: Yes. To be built into, otherwise the designer will do something. And this is one advantage the computer had over clay models. Is that, with some, you're taking the same language as engineers. So you can say to them back and say, well, why can't we move that LCD screen to just over their. Where as before hand you'd have a lump of foam or a lump of clay and they'd say well you can't do that.³³

JS: Just out of interest are you still using clay models?

CL: It does happen yes, but especially. Not, what we're doing here we've got a little rapid prototyping machine next door. An ABS printer, and we can just output some bits, 1/18 scale cars. These bits where done, this is an RCA student's work. [Pointing to a 1/9 scale model of prototype car in front of desk] but we can't do this size if you like. We can do smaller scale. But, in the car industry they want to mill out the full size car. Product design they're much happier with rapid prototype, but they'll still be using foam to rough out, try the form, capture certain, you know the stage here [points to concept design stage in original model of practice, fig 1]. Where this idea here, where it looks like they've got a physical model maybe, [points at sketch model representation on original model of practice, fig 1] maybe that's still sketch, but, to me, where designers using this tool at the moment aren't very clever it's creating the form, but sketching these bits on it. So rather, at the moment I will be the make and model on the model on the shop lines, they put on the light graphic they put on the screen [pointing to 3D rendering of car on original model of practice, fig 1]. Well their slowing down the creative process. Where they should be doing, that's a 3D object you're stopping there, and you're sketching on this shop line that goes across their [picking up the Dictaphone's and indicating the split lines and controls] they're painting on the button shapes, because what's the point in modelling them until you're convinced the product is... So that's

³¹ 02CL_Q1 Process

³² 02CL_Q1 Process

³³ 02CL_Q1 Process

what I'd say on that. So yes, there's nothing wrong with that process, that's sort of how it should be. The tools are there to use it earlier get people involved in it earlier...³⁴

JS: Ok, thank you very much for your time. That's all been most helpful. Particularly interesting what you had to say on your early adoption of digital technology and your opinions on where design practice is now which regard to tool use within practice. Thank you Chris.

Practitioner Interview: Pr02

Practitioner Interview	Pr02
Date/Time	21 st July 2009/ 14:00-14:35
Consultancy	XXXXXX Design Ltd
Interviewee	XXX XXXX (TT)
Position	Designer
Interviewer	James Self (JS)

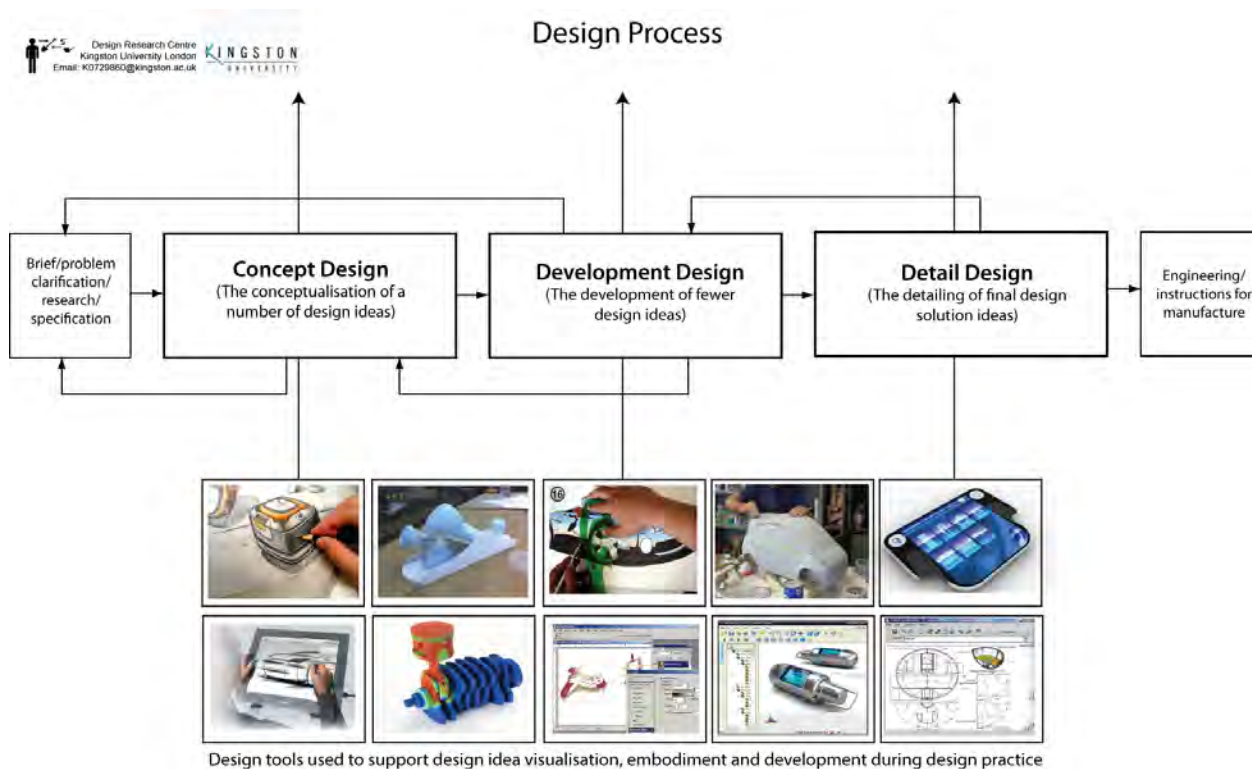
JS: Ok, given what I've just been saying about my research around the influence of design tools on practice. Could I first ask you about your use of tools? I mean, take sketching. Is sketching a tool you would commonly use during concept design?

TT: Yes, I would I guess. I think sketching is used throughout. I think a lot more in the initial phase of the design concepts. But yes, I personally sketch all the way through the design process. You, just, even if it's little details to go over concept themes.

JS: Ok, first off, could I show you this model of industrial design practice (fig 1.)? This is based on a model from a design researcher and academic, Nigel Cross, based at the Open University up in Milton Keynes. I would just like you to look at the model and I would like your opinion on it with reference to your own work?³⁵

³⁴ 02CL_Concept TOOL's

³⁵ 03TT_Q1 Process



TT: So you've got a brief, problem clarification, research, specification err [inaudible, considering the three stages of the model of practice, fig 1]. Ok.

JS: So what's suggested here is that design practice might be split into three phases. You have this phase here [points to research phase in model of practice] which is the identification of the problem.

TT: Research.

JS: And then from there you move onto problem solution. And then off into engineering design for manufacture.

TT: So there are almost three sections?

JS: Yes, however, in my research I'm concentration on this area here [pointing to problem solution phase in model of practice – concept, development and detail design (fig 1.)]. So, obviously they are iterative and design moves back and forth, but I'm interested in the way deign tools are used to visualise and embody ideas within this area of practice, the search for problem solutions [points to concept, development and detail design]. So, this model of practice suggests that problem solution is also split into three overlapping areas of practice: conceptual, developmental and detail design. Is that how you see your own practice?

TT: [After a minute of contemplation] yes, I could agree with that.

JS: And so this model suggests that design practice starts with a plural approach to designing and that that process is gradually focused as the designer moves through the process of problem solution before manufacture and after the brief and research phase.

TT: Yep, I would agree with that as well.³⁶

³⁶ 03TT_Q1 Process

JS: Ok, so. In that case, thinking about your conceptual design work, at the front end of design practice, could you talk about the tool or tools you use, that you find most useful to use in the support of your own conceptual design work?

TT: So in the initial concept phase?

JS: Yes.

TT: We would, generally, initially start with sketching, quite a lot of sketching. And then, a little bit of CAD at that stage, because we would also model up the package assumptions to sketch around. So, yes.³⁷

JS: Sorry to interrupt, but by package assumption you mean the dimensions of the internal technology that must be inside the product?

TT: Yes, that's what's going into the product itself. So, we make an educated guess, a good assumption, based on existing products and the component sizes of competitors and the current, if there is a current, product. And then we have something loosely to sketch around so we're not kidding ourselves in terms of size. And then, then it'll be a case of, sketching as well as working. Getting into the workshop and making some quick foam models.³⁸

JS: Ok, so sketching, and the sketch modelling, you do that here at the studio?

TT: We do that. We have a small workshop which is reasonably equipped. And then, it's a case of sketching, foam models. Learning from the foam models. Maybe sketching a bit more. Foam models, until we think we've, kind of narrowed it down to some themes, as some concepts, directions. We, we're happy to present to the client. And they just typically will be about anything from four to six concepts, possibly, depending on the product. And then that initial phase gets presented to the client, which we could probably hone down after that in the development stage to about two.³⁹

JS: So thinking about the sketching you use during conceptual design, and your sketch modelling, this may seem like an obvious question, but I would like you to try to focus on the tools you use, could you suggest why you feel that sketching and sketch modelling are the most useful tools to use during conceptual design practice, as apposed to using, say, 3D digital modelling software?

TT: If you go 3D, we can often, sometimes we go 3D packages earlier on in the concept design phase, but I think it can be constraining in terms of flexibility and speed at which you can churn out concepts. Because, especially if you go down the 3D route, you got a lot of constraint on figuring out. You don't really know what you're building.⁴⁰

JS: Oh Yes?

TT: So you got to try and figure out what you're building and design at the same time. Where as you can be a lot looser in foam and sketch.

JS: What you seem to be suggesting is that...

TT: You can explore more designs and cover a wider range of options with sketch and foam, in a shorter space of time than you can possible do in 3D.⁴¹

JS: So, the affordance of sketching and foam modelling is its ability to enable you to move through a number of design ideas. It's ability to support the generation of many ideas quickly?

TT: Quickly, yes. Very quickly.

³⁷ 03TT_Q2/Q3Concept TOOLS

³⁸ 03TT_Q2/Q3 Concept TOOLS

³⁹ 03TT_Q2/Q3 Concept TOOLS

⁴⁰ 03TT_Q2/Q3 Concept TOOLS

⁴¹ 03TT_Q2/Q3 Concept TOOLS

JS: To quickly explore?

TT: Explore, yes it's just certainly that element. It doesn't have to be. It could be just a small detail that you want to explore. Not necessarily the whole design itself. And there's no other way, I don't think of...It's also very much a, a sculptural thing, for certain products as well. You know. And there is only a certain amount you can do in 2D. And you discover a lot, especially with the tactile products. How it's held and how it feels. You can't do that in 3D. And that's quite an important element.⁴²

JS: Do you have a 3D printer or rapid prototype here?

TT: We do. We have a 3D printer.

JS: And so you use that in the same way that you would use sketch modelling? Do you, to support your conceptual design work, to achieve the tactile element through the digital?

TT: No we wouldn't. We wouldn't because it's, it's quite time consuming. Say, to print out maybe a cordless telephone handset. That will take about ten hours to print. So, you know, you've got to model it first. So you can spend, maybe a day modelling then you've got a whole day to print, that's two days already. Where in foam I could have made maybe ten!⁴³

JS: Interesting. Could we go back to the physicality of foam modelling? You talked about being able to hold the form of the concept in your hand. How does a 3D print, if at all, differ from a process of sketch modelling? As you know the printer is literally printing the geometry from the screen, as well as your suggestion about speed.

TT: We would very really go to 3D anyway without having a foam model to go by. We'd have something to give us some guidance into what we're doing. We wouldn't go straight into 3D. So we would get that from the foam. We would get that from the feel of it, from the foam models. So we wouldn't really rapid prototype at this stage. It would only really be either towards the development phase or towards the end, where we're just sort of proving the design really.⁴⁴

JS: OK, interesting. Can I ask you; have you got these cintique graphics tablets here? [Pointing to image of tablet in model of design practice, concept design, fig 1]

TT: No we don't. We don't. I think it's because we rarely work with...When I first started, that was about eight years ago, I, we did a lot more Photoshop and Illustrator renderings. But, more and more so now we generally sketch, foam, and then do some loose 3D, which we call blobs essentially. They're without much detail. They describe the overall form and main elements. Which we would then, most of the time, apply the graphics, keys and certain detail to as a 2D flat layer. So those sorts of details don't need to be modelled in. There's no sort of time wasted really. It's more efficient.⁴⁵

JS: So this loose 3D work you're describing comes slightly down stream of this [pointing to concept phase in model of practice, fig 1]?

TT: It's, a little. It's, we could, we could, and we can, depending on the project and depending on the time scale. We can actually do that towards the end of this phase [pointing to conceptual design phase, fig 1]. But defiantly it happens in this phase [pointing to development design, fig 1]. But it, generally more often than not, it does happen. We do some sort of loose 3D. Just so we're not kidding ourselves in terms of the shape and the form and we can fit it in within the constraints of the package.⁴⁶

⁴² 03TT_Q2/Q3 Concept TOOLS

⁴³ 03TT_Q2/Q3 Concept TOOLS

⁴⁴ 03TT_Q2/Q3 Concept TOOLS

⁴⁵ 03TT_Diversion_TOOLanalysis

⁴⁶ 03TT_Q4?Q5 Development TOOLS

JS: And that loose 3D work, is it a case of you taking your concept sketches and building on them? Maybe you're, do you, for example, still scan them into Photoshop and then you use that to manipulate this loose 3D work?

TT: We do sometimes scan sketches and use that as guidance, in terms of rough sized and form, just in elevation form, obviously. We certainly do that. What we can also do is quickly do some illustrated line work around our sketches to tighten it up, and then export those lines as a DXF⁴⁷ into the packages and we'd have, maybe, a top and side view possibly. Then that gives us a framework to build our 3D around.⁴⁸

JS: If I may take you back slightly. When you're working on these 'blobs', the loose 3D work you described, is it, you're doing it in order to get clear in your own mind, the design.

TT: Yes

JS: Is they also used later on for development design where you're, for example, presenting to clients?

TT: Yes we would. Because the reason we do a 3D, loose 3D, at this stage is because, and apply graphics onto it, in terms of keys and details, is that, you can really show different key options on the same sort of overall form of maybe a base or handset. And also, in terms of getting visuals, it's more efficient, in terms of time and the images you can produce, in the sort of quick renderings we use; are 3D package is NX5⁴⁹, what we can model in. And we use seminal 4D to do our renderings. And we would typically actually present, loose 3D mapped on 2D, as the concept phase presentation. Because we can get 3D elevations, three quarter views which, you're limited if you stay in Illustrator or Photoshop. You're really limited to elevation shots. Unless you spend a long time sketching, like a nice three quarter. And then rendering it but really we don't have that. We're not afforded that time really, the luxury of that time. So, in terms of what images we can choose to show to the clients, and equally, reducing the risk on ourselves, that we, pretty much, prove that all the components fit within our design and the size it will be will probably only vary about ten percent. Because we have roughly 3D design.⁵⁰

JS: And that roughly 3D work is then taken to the client and you then have your client meet where?

TT: We would generally have a presentation after this research stage [points to research/brief on model of design practice, fig 1] so that we would, every bodies on board with what the goals are, what the challenges are and what we're setting our to achieve. Then, we have a presentation after this concept phase of, and we would agree, out of maybe six directions we would agree on two.⁵¹

JS: And so your communication, the way that you communicate your conceptual ideas during that presentation, you're using the 3D blobs, loose 3D in the presentation, and then map on detail as you said, rather than your sketch and foam models?

TT: We have depending on the client, presented sketches. But more often than not, we would loose 3D, map on 2D.

JS: OK interesting. Now moving along in the design process, when do you go onto start using 3D proper?

TT: Then we would, again, probably still do quick 3D at this development stage but maybe introduce more detail. We will put in, sort of, the main keys, possibly. Maybe without any, sort of, complicated surfacing, but, the loose form of the key details into this phase [pointing to development design on model of practice, fig 1] because we only have two to focus on. Maybe two to hone down in on. So we're

⁴⁷03TT _AutoCAD DXF (Drawing Exchange Format) a CAD data file format developed by Autodesk for enabling data interoperability between AutoCAD and other programs

⁴⁸ 03TT_Q4/Q5 Development TOOLS

⁴⁹ 03TT _NX is the commercial CAD/CAM/CAE software suite developed by Siemens PLM Software.

⁵⁰ 03TT_Q4/Q5 Development TOOLS

⁵¹ 03TT_Q4/Q5 Development TOOLS

afforded more time really and we know what we're doing because we have the loose 3D and the foam model to go by.⁵²

JS: So the outcomes of this [pointing to conceptual design phase on model of practice] stage here.

TT: Yes, exactly.

JS: Which is what you might present there [pointing between concept and development design]

TT: And this stage [pointing to development design stage in model of practice, fig 1] we may print. Sometimes we do some times we don't. It depends. But if it's two concepts, we would, yes, depending on the time constraints, we could, we could 3D print at this stage or we just, we remake the foam models again. But we, based on, sort of, the 3D data we know exactly what's the designs doing.⁵³

JS: Do you ever have any issues with communication when representing design ideas, where in you think your presenting something here [pointing to the start of development design in model] where your client reads the visualisation of your idea differently then you intended? Is there ever any conflict there, maybe they believe the design to be more committed than it necessarily is because of the way that the design has been represented, been visualised through the use of loose 3D or redone sketches or revamped foam models?

TT: Possibly...it depends on if they are new clients or if they're existing clients. Existing clients, I think, get how we work. But, I have seen new clients get confused. At this stage you've done 3D [pointing to start of development stage in model of practice] they see 3D. You've got visuals, it's, you know. Designs virtually done, you know, what else do you need to do? They don't really understand the other elements so much. But there is that risk. But it depends on the client if they're aware of our working process.⁵⁴

JS; Thank you, before we go on I'd just like to stick with your conceptual design tools. You said sketching and foam modelling are most important in working though conceptual design work. However you also mentioned that you don't show these sketches to clients during presentation, you prefer to use loose 3D and or redo your sketch models. Why not show the clients your conceptual work as it is?

TT: I guess it goes back to the fact that the sketches are used by us to quickly rough out ideas. We then give need to pull these together to present to clients, or show the clients the ideas in a way they can understand, present a number of chooses, like I said five or six clearly. If you where to just show a sketch book of ideas or part of a sketch book, clients probably might find it difficult to get a clear understanding of where the designs are going.⁵⁵

JS: So you're saying that different kinds of representations are needed for your own design work during conceptualisation and the visualisation of designs to clients?

TT: Yes, we use sketches; I think to get the ideas out, out of our heads. When we present to clients these need to be clearer, more clearly shown.⁵⁶

JS: OK, that's moving on from concept into development and detail design proper. You'd start using 3D and that 3D...

TT: That essentially gets two, maybe goes on to one. Then we would either, depending on how much changes are involved, we'd ether use, the development 3D and then make it so it's, we shell all our models. So, wall thicknesses. So all our data gets shipped to the manufacture, all they have to do is add in the engineering detail. So they would add the ribs the bosses the clips, but eventually all the shelled parts

⁵² 03TT_Q4/Q5 Development TOOLS

⁵³ 03TT_Q4/Q5 Development TOOLS

⁵⁴ 03TT_Q4/Q5 Development TOOLS

⁵⁵ 03TT_Clarification Q2/Q3 Concept TOOLS

⁵⁶ 03TT_Clarification Q2/Q3 Concept TOOLS

they shouldn't, they shouldn't need to change at all. Because that's the way we work. I know some companies provide loose 3D, at this stage to the manufacturer. They recreate. But...⁵⁷

JS: You're moving in quite deeply into the engineering, in that respect?

TT: In that respect yes. Well, it's also insuring what we show the client they're actually going to get at the end, because, you know, if you leave it to an engineer in the far east to interpret what you've done, you know, they could lose sight of what. They don't know what the goals and intentions are at the start. Things can get lost so we like to take control of that and make sure that all our external surfaces are used.⁵⁸

JS: What software. What do you use in that specification phase here?

TT: We, again, we use our NX 5 package. So we use that from sketch development to final engineering data really.

JS: Thank you. There is just one more part to this interview [Due to time limitations required to move on] So, imagine that your, Alloys going to New Designers, or a graduate show at a university. You're looking around the show, what is it in a student's ability to visualise their design ideas, to embody them, to represent their design ideas, that you look for. What are the skills set that you think is most useful for graduates to have to be able to express their design ideas?

TT: It's not insincerely how they visually communicate, although that is important. It's more their thought process we're really keen on. Because, we can teach them how to do that. It's not, necessarily how sexy or how glossy the images are. It's how thought through their process is and how well they communicate that to us.⁵⁹

JS: And so in order to access that thought process, what would you look for?

TT: We, we always like to see their sketch book and their development work. That really shows a lot more than just a nice glossy image, which a lot of people can do. But you know, we don't, we really want to know their thought process. The rationale behind that design, not just that it's nice looking.

JS: So what you're saying is, in a sense, there's something about sketching, again, we're coming back to sketching, there's something about sketching...

TT: Yes. The ability to sketch is relative, you know, it's not, it doesn't have to be really sexy sketches either. We're not looking for great artists, because, we rarely present sketches to clients. It's the ability to communicate. As long as you communicate through a sketch, that's the key requirement really. It's not necessarily that you're an artist and you're an amazing sketcher.

JS: So communicate, internally, to others in the studio and yourself?

TT: Yes. And verbally I think, when their presenting in interviews. They have to be able to verbally present. And show us; talk us through their thought process.

JS: So what you're saying, with sketching, it's a communication but it might also be described as, when you're sketching, you're doing something that communicates with others and yourself? For example 3D printing is a kind of communication and you are using that process to reflect on your design ideas. But there is something about sketching that makes it useful for understanding a designer's thought process. And so is more part of a designer's thought process in a more dynamic and engaging way. More so than 3D printing. As well as being a tool for communication?

TT: Yes, there is that. And you can see, you can almost understand their thought processes with sketching. Where, if you see a glossy image or you see a 3D print, you don't have any ideas of the thought processes

⁵⁷ 03TT_Q4/Q5 Development TOOLS

⁵⁸ 03TT_Q6/Q7 Detail TOOLS

⁵⁹ 03TT_Q8/Q9 Skills Set (Page 11)

involved. Where as, if you see sketches and lots of little doodles, you can actually, it's literally sketching, for most people, it's literally transferring what's in your mind directly onto paper. It's a dump of your ideas. You can't do that with a 3D package or with a print. And that's the Key thing for us to see. Because, I certainly, obviously, certainly when I graduated, having Illustrator and Photoshop rendering skills was quite important, initially to be useful. But, more often now that kind of thing's done in 3D so that some 3D knowledge and 3D CAD rendering knowledge is quite useful. But again it's not essential because we, we teach that here.⁶⁰

JS: So these are learned skills you think, or teachable at any rate?

TT: Yes, that can be taught. The CAD element can defiantly be taught. The creative and the thought process is, I don't think that can be, so much as such. That's what we're looking for.

JS: Ok, very interesting. Thank you very much for your time. I really appreciate it Tan.

Practitioner Interview: Pr04

Practitioner Interview	Pr04
Date/Time	Sun 16 th August 10:00-10:45
Consultancy	Samsung Design Europe
Interviewee	XX XXX (K)
Position	Senior Design Management
Interviewer	James Self (JS)

JS: OK. What I would like to do first is to show you a model of industrial design practice (fig 1.).This is a model based upon one from a design academic at the Open University, who does a lot of research looking at industrial design, it's a model based on his model. I just would like you to have a look at it all tell me what you think of this model of practice?

K: (picks up model of practice to consider it, fig 1)

⁶⁰ Clarification: tool Sketching

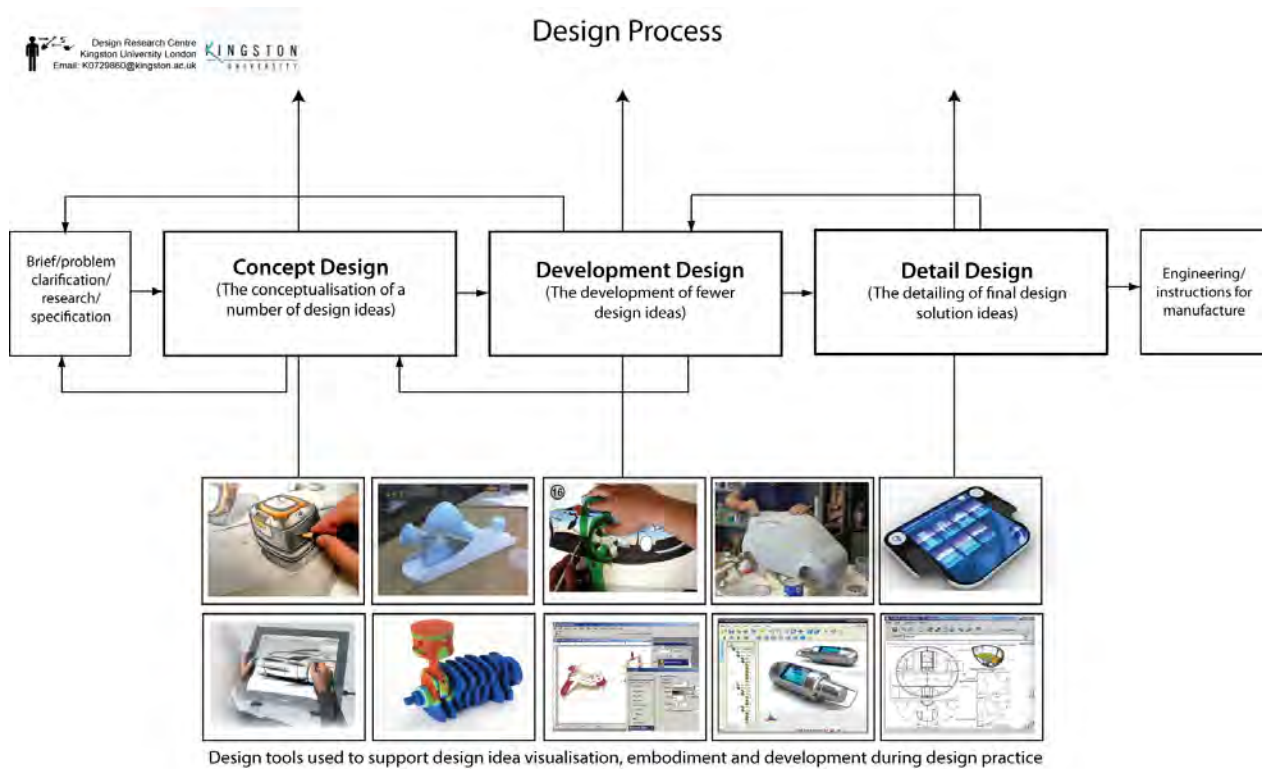


Figure 4: 3 Stage model of practice

JS: Cross, the academic that published this model, suggests practice goes through, at on end, design brief research, problem clarification, as he calls it. Then, onto a phase called conceptual design at the beginning of problem solution. This is where the industrial designers would come up with some initial ideas, some concepts. And then these move through, almost like a funnelling effect, where broad rough, less defined design moves through into a funnel where the design comes out here, where it's detailed design, before moving into engineering before manufacture. Before production (indicating on model of practice movement from concept through development design and onto detail and manufacture, fig 1). So there are three generic stages here; Concept, development and detail design. And maybe here (indicating point of change between concept and development) or here (indicating point of change between development and detail design, fig 1.) you might have a client meeting, or an internal review. And Cross also suggests this model is iterative, the progress of design may have to return to a stage before (pointing to arrowed representations of iteration on model of practice). There is iteration there.

K: Yes I think, generally, I would agree but it can depend on which [design] office you are. In a consultancy and in a corporate company it can be quite different. In a consultancy you have a client, that's all. In a big corporate company there are so many stake holders. So there is so many information to collect from the different channels [Inaudible]. It is more complex than when you have just one stake holder. In a consultancy you just have one client. With a corporate company it may be a conference or a marketing thing. Product planning change, engineer change, designer change. All the higher decision makers, people's opinion, things like that. So even though you suggest one design, a presentation, then they will have a feasibility meeting. Then, depending on that meeting it will depend on what you have to do. So you have to decide. So collect all the meeting results, what ever. Then you have to figure out. OK is there a one, one common direction or is there so part that is common, that all people like. Then, there, you have to make a decision. Ok that's a good idea. Yes, but I think you on this stage here (indicating concept design stage in model of practice) we explore more widely, open wide. So we a little bit ignore about that [stakeholder's opinions] because the reality. So on this stage [concept design] we don't too much take reality. We are a little bit more wide. We explore more. So we don't loose any, like, good idea. And then also it goes down. And at this stage we may have a meeting (indicating space between concept and development design on model of practice) and it keeps going down, and getting more close. You

become more reality. More close to the product in the market. Second thing is there are many different...you can make designs more and more, but I think I generally agree, (indicating concept design in model of practice). But here I think you should have (indicating stage before concept design) cooperate analysis. And then, and also you can put, if the budget and time allows, we normally, rather than just an internal opinion, we can have a focus group. So, rather than it just being us, we go to the consumer and say what do you think. From there we extract the result and then move on to the next one. That's often, normally after [inaudible]. You actually make a patterned product. And just to prove the market [inaudible]. When time and especially money allows, you can do this at each stage and then you can prove, you can become more close to what real people want with appearance and to design. But I think generally it's a good model.⁶¹

JS: Interesting, I had not considered the difference between the corporate and consultant environments and how that might influence practice. My research is interested in, in that case, these three stages here (indicating concept, development and detail design on model of practice) and the thing was that the use of different tools may influence the representation of design ideas. The embodiment of design ideas. The way the designer can visualise and communicate design ideas. So I suppose, industrial design practice can be split into to. The area you have just described – problem identification and analysis and problem solution. Interestingly, you've just suggested they mix together, with research coming back to here through concept and detail design (indicating iteration between stages on model of practice). What I'm interested in, specifically, is the way that the representation of the idea, through different media, of ideas influences practice at these three stages (indicating model of practice). I would like to back track and talk a little more about that, if that's ok?

K: Yes

JS: OK so taking the stage of conceptual design at the front end of practice, when you're getting your ideas together, what tool or tools do you most often use during your conceptual design work?

K: I think it should be the hand sketch and then quick 2D renderings, like Photoshop or sketch or quick 2D rendering. Some people does really quick 3D rendering. Don't worry about tangent continuous just quickly. Because with that you can see the potential design. Yes, I noticed, now days, you're talking about the tools. Some people do sketch. And I noticed now day's students they go like straight into the 3D. And also, like we have lots of different designers now. Some people like, we have a German guy which just goes quick hand sketches and then transfers to 3D. We do have like sketch like a 2D rendering then we go on to 3D. But now days 3D is more so quick and easy and more getting action. People attempt to do 3D, but I would strongly recommend students, they have to experience everything. Then later they can choose what would be more efficient or useful for them. Not only that, also what they are into. Which company they are working for, because each company has different needs. For example, there's a student, 'oh, I love 3D. I can do it easily. I don't worry about sketch, I worry about it. Then he hired some company, which is historically hand sketch is so important. So what stage of design solution is that needs a sketch what should he do? Maybe he's taking six months to do a sketch, or whatever. As a student they should learn how to use all tools. But 3D is so important now days, if you don't do 3D. Are you really a designer? So 3D is important but hand sketch is not just bonus it's the way to, anyway to [stressing 'anyway'] the first filtering down from the concept. Because some times, often, then you will have one project with three other designers. So when filtering down the process and then if you are selected then you will become the designer and carry on. So always the first stage is a sketch.⁶²

JS: So given that hand sketching is important in design, and you talk about quick 2D rendering using software, adobe Photoshop, illustrator, could you go albeit deeper in saying why you think sketching, quick 2D is so important to concept design practice. Could you talk about the character of those tools that make them really useful for conceptual design work?

K: I think first of all just because like to draw in 3D about this [picks up Dictaphone] and hand always depending on the computer. But hand sketching is much easier. So, if they do conceptual thing in 3D. What they do, they found one idea and then stop for about 3 hours. And then they found another idea and then stop for about three hours. At the end of the day, two days later OK, Do some conceptual work

⁶¹ 04K Q1_Process

⁶² 04K Q2/Q3_Concept TOOLS

individually and then come back to me. And all my designers come back. With the first designer, he comes back with two concepts with the shiny 3D graphics, the other guy's hand drawn, really rough. He takes a different method and says hey, it looks like this, a different approach. So, I think, He has ten varied ideas and the two shiny ideas. I would like to have the ten ideas because I can see the potential of the design. So the first stage (indicating concept design) should be wider rather than stop on one or two of the designers. Because, the first initial stage, when you explore, be more creative I think then you find the compromise rather than just the first ideas and then into 3D.⁶³

JS: So what you're saying is there is something about these tools, sketching, that gives the designer the ability to explore in a lateral way, so you can go on from one idea to another idea to another idea and there's flexibility within sketching that gives you the ability to explore more widely?

K: Yes.

JS: As apposed to 3D. You said they looked quite shiny, but the constraint of 3D CAD means that the designer doesn't have the ability to widely explore their design ideas.

K: You can make a graph like 3D becomes like a long stick (indicating a long line in the air) because that stands alone, so the variety is shallow. But the hand sketch is quick, Ok, it works. So that (indicating 3D) may be a little bit shallow. So part of this should be widening and sketching is then getting longer but wider (drawing a horizontal line in the air). You may think about that kind of graph. So it you think of that process, if the first stage is shallow then this stage (indicating development design) getting longer and the last one (indicating detail design) has a long depth. Everything is seen, the engineer, engineering.⁶⁴

JS: Interesting. Thank you. Now, just a quick point of clarification, you said when your designers' come to you like to see lots of different designs.

K: At that stage (indicating concept design)

JS: At that stage. So would you say there is something about sketching that allows you to see into the thought process of an industrial designer? Where as if you see a shiny 3D image...

K: Yes, that's right. Once you see the 3D rendering people perceive it as the final design. But when they see the sketches then they can see the process, yes the process of the design. Not the case with the final 3D rendering.⁶⁵

JS: So do you that some times, unwanted in your representation of ideas. So if you're presenting the 3D rendering internally to a stakeholder, is sometimes the fact that it looks too committed to the idea presented?

K: Defiantly. For example, on one project we would normally have two or three stages of presentation before the final mock-up. At the first stage we never show 3D because that has gone too far in giving the wrong impression. Even though, I don't think we just do sketching or something like that. Some people even do quick 3D renderings, just a screen rendering or something like that. But I just say do whatever you want. So some people do sketches, some people do 2D renderings some people do quick 3D. Yes, so however. OK, that's internally. When we present to a final customer we make more of the same method of designing. So it should be Ok you do 2D, you do 2D you do sketch. I say Ok at this stage we're presenting the sketch. Then we have one or two days so we. I say this, this and this concept and then this presenter will have in hand sketch format. So in two days these will be the people bringing the reworked hand sketches.⁶⁶

JS: So are you modifying the hand sketches in some way? Changing them in some way before sending them to the stakeholder or client?

⁶³ 04K Q2/Q3_Concept TOOLS

⁶⁴ 04K Q2/Q3_Sketch CAD comparison of TOOLS

⁶⁵ 04K Q2/Q3_Concept TOOLS

⁶⁶ 04K Q4/Q5_Development TOOLS

K: Yes

JS: So why do you feel it's necessary to modify the hand sketch, to change it before you present to the client?

K: What I'm saying, I don't say to people the format is hand sketch or 2D to explore the idea. So I just let them come back with different formats. When we send it to Korea we couldn't have one concept as a 2D model and one concept as 3D. It's unfair. They should be all fair format, rather than relying on when they judge the concept, then depending on the format, we should make sure the idea the concept. That's why it should be all fair. A fair format and all formats are different.⁶⁷

JS: But you do send your sketches, they are all the same, but you would send the sketches as they are to the clients?

K: Yes, all depending on the product. At Samsung [delete for publication] there are so many different products, mobile, wall appliances. And each has a very different character? So I know what character they need at each stage. But it also all depends on the client.

JS: Moving on to development design then. So (indicating the model) we were talking about the depth of design increasing, moving onto development design, what tools would you then start to use more of to develop these conceptual ideas?

K: In our office, normally, concept design is like, let's say, eighty percent hand sketch, 20% [inaudible]. We actually hand sketch and use one more layer to line drawing, do you know Velium?⁶⁸

JS: Velimum?

K: A kind of line without any shade or colour. So we do a hand sketch and then line drawing. The line drawing benefit is, with hand drawing there's no consideration of scale, just a 3D drawing. So from the line drawing what we can do is prove there that Ok that concept interesting it's a hand sketch but we don't know whether it's going to fit into this. To check that ability we do line drawing. So it's like a true understanding of the scale.

JS: So you're checking the package the internal dimensions of the technology?

K: Yes. Also design becomes more final.

JS: And so that's during the development design?

K: Yes, I think the first stage of development design.

JS: Is development design the time when you would start to bring in rapid prototyping tools and 3D modelling proper? Would you start to use these digital technologies during development design, once you've decided on a direction?

K: I think so, development design. And then that line drawing. Then we use Photoshop or illustrator for the colour (emphasised) the shape (emphasised).⁶⁹

JS: So you're using Photoshop and line drawing as the design progresses during development design?

K: Yes, line drawings first and the Photoshop.⁷⁰

JS: Then Photoshop and then onto, would you start building physical models at that stage, sketch models, foam models? Do you do that at all?

⁶⁷ 04K Q4/Q5_Development TOOLS

⁶⁸ 04K Q4/Q5_Development TOOLS

⁶⁹ 04K Q4/Q5_Development TOOLS

⁷⁰ 04K Q4/Q5_Development TOOLS

K: We did. But now days, because we have a 3D printer we are able to.⁷¹

JS: So you don't have a dedicated workshop as such?

K: We do have a workshop, but the 3D model is in the computer and a couple of our designers can't use the 3D so they keep going in there. Sometimes when we can't print we might use it.

JS: So generally speaking you would use the 3D printer?

K: I think so, like 90% of the time.

JS: What would you say are the benefits of a 3D printer as medium of representation as apposed to getting some foam or clay and doing it by hand, doing it the conventional way rather than the digital way. What are the advantages?

K: It's fast. It's exactly what you see is what you get. Hand is still can be, let's say, 2mm off or, but this one is exactly what you design on the 3D (digital model) you get it what you want, so accuracy and speed.⁷²

JS: Do you use at all appearance models?

K: We do. Every product you see in Samsung is, we make an appearance model first, so there is a, yes it's very important.

JS: And where does that model come in, is that towards this area, development design?

K: No. that one is almost, rather than evaluate the design for designers, appearance design is for the final decision making for production. For the higher people, for the stakeholders.⁷³

JS: And, Ok you make an appearance model using rapid prototyping technologies?

K: No, that's a proper model. You can't distinguish between the real products. It can be singing and dancing, all the lighting all the sound.⁷⁴

JS: And do you do that in house?

K: We use a 3rd person.

JS: And they are all rapidly prototyped from a SLS or SLA for example?

K: No they are all from traditional CNC machining.

JS: Interesting. So you use 3D printing to support development design and then you're talking about using a final prototype for detail design.

K: Here (pointing to engineering for manufacture on model of practice). When all design is finished we send the data to the model makers and then go to production with that. But between this appearance model and a 3D modelling, sometimes we often have the mid-term-model, as we call them, which is we send data to model maker. This stage is the same process (pointing to development design). But it won't have all the detail, like buttons and all that, just the basic proposal. For this one we have one or two pieces and then spray it to give colour. So we're basically aren't changing the overall form. And then the final appearance model we have all the detail.⁷⁵

⁷¹ 04K Q4/Q5_Development TOOLS

⁷² 04K Q4/Q5_Development TOOLS

⁷³ 04K Q6/Q7_Detail TOOLS

⁷⁴ 04K Q6/Q7_Detail TOOLS

⁷⁵ 04K Q6/Q7_Detail TOOLS

JS: So that mid, that mid stage model that does doesn't have all the functionality, all the detail on it. Obviously, you could build that model in 3D software and have it on the screen. What I mean is you can have a 3D digital image of your design using, I don't know Maya or Max or whatever you use. You could have that?

K: Yes

JS: But you still find it necessary to have these 'mid-stage' physical models. Why is that? Why don't you just stay with 3D digital representation? What is it about the model?

K: Especially, especially the design should be in your hand so you can feel and touch, you can never replace that, what the human can feel. I heard the humans five senses, the quickest that goes to the brain is actually that of touch. So when, you should hold it then you can feel that [inaudible]. They invest in a programme which is almost in real time you can change the colour and. At the end of the day that one is in the screen of your mobile phone, floating around never, never being seen.⁷⁶

JS: So there is something about the physicality. The ability to touch. That's interesting. Could I just rewind for a second back to concept design and using 3D printing, because, I suppose, what you're doing when you 3D print is making a digital representation and then printing it off. Having it checked, change, making another digital representation, printing it off. Is that how you use the 3D printer?

K: Yes, it's like a very quick sketch almost, but printing out, normally a mobile phone, printing out a one hour. So it's just quick.⁷⁷

JS: Could I ask what software you use for that?

K: It's all different depending on the designer. Personally I'm using Alias.

JS: OK, that's interesting. And then with detail design you have your final model here which you then show to your clients into manufacture. And I suppose, being in a large corporate organisation, as you are, the same company is responsible for manufacture, different from a consultancy, obviously. So you take the design through manufacturer.

JS: There's just one more part to this if you don't mind? Then we're finished. If, for example you go to a university or new designers at the Business design centre in town and you're looking around, let's just say for example, you're looking around to employ a graduate designer and you're looking at their work and talking to them, what would be the skills or the skills set. The things you look for first in their design work? Do you look at their 3D work? Do you look at the models they've made, the rapid prototypes? Do you look at the sketch work?

K: Creativity I like to see. Creativity first, because in the end, at the end of the day 3D is just a tool. It's just a hammer or a saw, that's all. But a human's brain is where the creativity is. We can employ pro 3D designers for you or what ever. So creativity first and then the presentation. How to deliver ideas.⁷⁸

JS: An ability to communicate?

K: An ability to communicate. That can be, actually, that can be, include everything. The attitude and the language skill.

JS: So you're looking for this ability to be creative. And so do you, I suppose it's obviously different for every graduate, but do you find you're able to judge creativity by their ability to represent ideas in a certain kind of way, through a certain media or tool? What I mean is if you are looking at the model they've made or the 3D rendering or the sketches, you're able to judge their creative ability through their 3D work more, through their use of sketching more? Or would you just say it's a package it's a whole?

⁷⁶ 04K Q4/Q5_Development TOOLS

⁷⁷ 04K Q6/Q7_Detail TOOLS

⁷⁸ 04K Q8/Q8_Skills Set

K: Yes, I think so. I think so. Even like, people. Ok there's a guy 'A', 'B'. 'A' has like not resolved 3D rendering and 3D work. The other guy has like, [inaudible] thing. But when they bring the rendering I can see, Ok these are more what it looks like real, from 'A'. From 'B' I don't know, it looks more sophisticated, even like less technology I guess, more sophisticated or the right way to deliver their ideas. So, we don't like to much very shiny chrome. I think 3D we check later, when we are interviewing. I mean we are a blue chip [company] so we interview lots of students. Actually we talk to each other and how he's doing and his creativity. And then check, 'Can you do 3D?' Yes? Ok. No, 'um' [laughing].⁷⁹

JS: There is just one more point I would like to go back to if I may. I'm sorry but I feel I would like to have another go at this if that's Ok? This might sound to you like an obvious question but I'm going to give it to you and see how we go. You said sketching is important here (indicating concept design stage in model of practice). Is sketching also important during detail design? Do you use sketching to work through your ideas at the end of development? Towards the back end of practice? Do you also sketch here (indicating detail design) as well?

K: I think so because it's a kind of journey and you still have to find out what is this detail (indicating split lines and button details on Dictaphone) because this is the kind of face of your mobile phone. And to have this shape (indicating bevel at edge of Dictaphone) the designer should have thirty or fifty different shapes of this thing. We can't do on...So you just do. Normally it's like [inaudible] maybe this detail looks good...⁸⁰

JS: But you couldn't do that on 3D software or work it out using a 3D printer?

K: You can do it. But still, it's the same thing; you can only explore two or three. So, that all takes time. The hand sketch is so quick. Because, let's so to do his one (indicating split line on Dictaphone) you just [whistling noise]. But in 3D you have to make four lines, have to make a rectangle. It takes time. So a hand sketch is quick or looks good. Then maybe try 2D and 3D.⁸¹

JS: Do you use these cintique graphics tablets (indicating image of tablet on model of practice)?

K: Yes. We used to have one guy that had one, but, he bought one because he said it's quite interesting, 'I want to have this'. And um, at the end of the day he did nothing with it.

JS: No?

K: I think that's quite popular in vehicle design rather than product design.

JS: Why did he decide this [cintique tablet] was not of great value, do you know?

K: I don't know. If someone can almost use it in the same way as paper. And you can, because that's the concept isn't it? But actually to do that it's quite...you have to learn, almost another programme. I think that's right. It's not intuitive enough maybe. It's not...⁸²

JS: have you ever heard of haptic devices?

K: I know haptics is to do with touch.

JS: Yes that's right. There's a new tool. Not new now, it's been around a little while now, the technology came out of MIT's touch Lab. You have your model on the screen and by moving the pen you can feel and manipulate the geometry of your model on the screen called haptic force feedback. This gives the designer the ability to feel, like you were talking about the importance of being able to feel the mobile phone in your hand, it's giving the designer the ability to be able to feel the digital 3D. Unfortunately it's

⁷⁹ 04K Q8/Q8_Skills Set

⁸⁰ 04K Clarification on Sketching TOOL

⁸¹ 04K Clarification on Sketching TOOL

⁸² 04K Deviation TOOL Digital Sketching

also had some disappointing reviews because you can only feel that much (indicating the end of a ball-point pen). The designer can't get their hands around it.

K: May I generally say though. 3D is very, very good. It's generally opened all designers' eyes, the ability to present, especially the presentation of hand skills. There's a limitation at the end of the day. But 3D rendering is a skill. Have you heard of Hypershot.

JS: No I haven't.

K: it's a new kit on the market. It's a rendering tool. It's such a cheap and easy. Like everyone is starting to use it. And then it's so it's just manly you bring your stuff and it's almost a click it's almost a drag. A quick drag on the screen. And then you just click and then it's so easy so. Yes I think 3D is just. I think it's nothing. I can't say which one is the best, they are exactly the same, but it's how you use them all. But I would say Ok hand rendering, it's all mixed. So the first stage you do quick...⁸³

JS: So what you're saying is that they're tools and it's the ability to know how to use them best for you're self in order to get the results. Sketching, you can do this and this, 3D rendering. But then you're saying theirs a tool for every purpose?

K: You know the celebrity designers, like Jasper Morris Use; we all do work with them as well. So I visit them. And I not interview them but a talk and we chat. They often don't use 3D. Even when they do sketching, they don't draw in perspective, always dead front and dead side because it's a very graphical approach. But maybe their assistance they draw it and give to them their assistance and they do the 3D. But some other people, I know one guy who is straight into 3D. Another one that. Last year there's a department called engineer at the RCA? I forgot its name. Basically what it is, the engineer paid the student, who wants to be a designer, and they come to this master's course for two years and train as a designer and become a designer. One of the guys being employed he said if there was no 3D software I wouldn't be a designer. So he is bad a the sketch [laughing]⁸⁴

JS: [pretends to laugh along]

K: So yes I think it's equally so. But it seems to be 3D things getting more. May be this one becomes so intuitive to use [digital 3D] then it will completely take over

JS: And that's the case. So you're saying that's the key

K: I think so.

JS: If it gets to a level where it can be used in the same way as sketching.

K: I heard 3D software in the future, the future of 3D software, is not icons between [pointing to screen of computer on the desk] you actually become, like a movie, your almost become clay. And what you do here is the screen is done by the way you think.⁸⁵

JS: So advances in Human-computer interaction. Thank you very much. Thank you

K: My pleasure.

Practitioner Interview: Pr05

Practitioner Interview	Pr05
Date/Time	Tue 18 th August 2009 15:00-15:45
Consultancy	XXX XXXXXX

⁸³ 04K Deviation CAD that mimics TOOL sketching

⁸⁴ 04K Deviation TOOL sketching in practice

⁸⁵ 04K Deviation TOOL CAD futures

Interviewee	XX XXXXXX (EG)
Position	Senior Designer
Interviewer	James Self (JS)

JS: I'm interested in the way that industrial designers and product designers are using different kinds of representations of their design ideas; different kinds of embodiments to communicate design intention during the design process. If I could just start by showing you a model of the industrial design process, based on a model by an academic called Nigel Cross. I would just like you to give me your reactions to this model given your own experience of industrial design practice, (presenting fig 1: 3 stage model of practice).

EG: OK so we start here (indicating front end of model of practice, briefing/research stage) yes.

JS: So it starts here (pointing to briefing/research stage) and it goes through these three stages moving off, in the end, into engineering design. Although these arrows represent iteration (indicating iterative return arrows running through concept, development and detail on model of practice). So perhaps you go through these stages but they're overlapping and iterative. But, generally speaking, what Nigel Cross suggests, is that design sort of filters through these stages. It starts off quite wide and narrows down (indicating direction of process and far left to far right on model of practice, fig 1).

EG: Yes. I would roughly agree with that. Yes. I suppose this loop here (indicating returning arrow between concept design and brief) might represent the brief might be changing as a result of something that's happened in the conceptual stage. I mean the only thing is that whether that is something that is done outside or in house. You know, obviously sometimes, some clients can have quite a specific problem, a specific brief. Where as sometimes it's very open, they just identified, perhaps, a small area or they want you to identify the area. That can take up a lot more time. But yes, that's pretty much the way we work. So the concept design, yes. We would carry out a lot of research as well that would inform that (indicating concept design stage in model, fig 1). I guess this is how most industrial designers work though. And then, yes, generate a number of options. Yes. Yes I would say that's pretty much it, yes.

Sometimes there's stages after here (indicating detail design stage) where you have extra products to feed onto it or improve once; they come back to you and 'can this be improved, changed' but I suppose that's a separate project at that stage.⁸⁶

JS: OK, so given that. My research is particularly interested in this area of industrial design practice (indicating concept, development and detail design on model of practice) where you've got the problem identification, the brief, the research here (pointing to first stage in model) and then you're going into the representation of design ideas through visual communication. So the study is really concerned with what's happening concept, development and detail design. Again, obviously, industrial designers do, sometimes, move into the engineering design?

EG: Yes we do. We would call that detail design there really (indicating final stage in model of practice). I suppose where we normally work is, yes, we produce a number of conceptual designs. Those would generally be sketches. Mainly because they're quick to do and we can, you know, you don't have to concentrate on the detail. You can just; you just draw the most salient points. Normally also, in between here (indicating gap between concept and development design on model of practice) we have, that's generally the point where we'd have meetings.⁸⁷

JS: in between concept design and development design?

EG: Yes, or during. But generally I suppose for quite a small project, like this thing on the right hand side, which was a food chopper (indicating sketches of conceptual development displayed on wall of conference room). So the brief was fairly plain to us. We were told, 'we want a new food chopper

⁸⁶ 05EG_Q1 Process

⁸⁷ 05EG_Diviation TOOL Sketching

product'. We were actually given some other ones that were out there and told we want to have improvement on these. These were the sort of vision. The price point was given to us. So the first stage, this is what you're talking about here (indicating concept design stage), was a series of sheets like this (again indicating sketches on the wall to the right of the conference table) Those are the actual sheets that one of our junior designers drew and then we scanned those in. And then those were numbered clearly, with the features clearly [inaudible] top corner. And they were sent through to the client. Then they came back. We sort of encouraged them. Said right, OK, pick one with the bases of other features.

From that is the development stage. This is a quick project, bar in mind. This is probably about two weeks work. In the development stage we would then, sort of, incorporate those features together. With this sort of project we keep that still quite sketchy. That will be sent through for approval. Once that's approved, we then very quickly draw it in 3D. And that would be sent directly to the factory they use, which happens to be in the far-east. So that's how that one worked. Very, very straight forward project actually.⁸⁸

JS: So, when you're thinking about you're conceptual design practice, you said things like you would quickly sketch or you would do some, a lot of sketching, you've described these sketches on the wall (indicating the sketches discussed by the interviewee)

EG: Yes.

JS: It sounds to me that one of the most important design tools that you use to support conceptual design practice is the sketch? Would you say that..?

EG: Oh defiantly and there's probably two aspects to that. Firstly, we would, as a group of designers. Say if, a mean some projects we'll all work on it at this very initial stage if you like (indicating concept design stage on model of practice). You probably split that stage in half. First half will probably when we've got the brief, we come together, or me and say if its Paul or if it's me and Pete or Paul and Pete or whoever, and we'd each produce sketches for that and then talk about it amongst ourselves. And then, they might be, I don't know, somewhere between twenty different varieties let's say. I think at about that point I think.⁸⁹

JS: That's an internal brainstorming?

EG: Yes, yes. But it involves sketching primarily. And in fact, it's not necessarily brainstorming in terms of us all sitting down in front of the table. But, say perhaps while we doing some other more hard nosed detail work, it's an opportunity to stop, to sketch something out. We all have books like this (opening a sketchbook onto the table). And so, like these little sketches here just to explore the ideas, while you're going along. So not really structured but then when the time comes to have a meeting to discuss that, you can refer back through your book.⁹⁰

JS: And those meetings, they are internal meetings at that stage [concept design stage] with other designers?

EG: Yes, yes. And then from there what we'd do is we'd pick out the features that we agree upon as being the most relevant.⁹¹

JS: And once you've picked out those featured from your sketches, then what would happen with the sketches?

EG: One person would then develop a number of those. So it could be, probably at least three we always try to offer. But up to say, ten. It depends on how much possible scope for variety there is and whether we

⁸⁸ 05EG_Q4/Q5 Development TOOLS

⁸⁹ 05EG_Q2/Q3 Concept TOOLS

⁹⁰ 05EG_Q2/Q3 Concept TOOLS

⁹¹ 05EG_Development TOOLS

feel that, you know, it's worth showing all that. And then one person would then develop those up. So that they're all in a consistent hand.⁹²

JS: When you say, develop them up, the sketches, what do you do them to manipulate them to a form that you feel is suitable to communicate with the clients?

EG: Usually we try to be pretty quick at this point, so we don't spend too long on it. But, for example, those sketches up there, (again indicating the concept sketches next to the conference desk) which you see they're just pen with a bit of colour added. What we'd do is draw them in a fine line pen. Scan them in and then probably put a splay of colour on in Photoshop or something like that. So that it's quite quick to do each one. And we can get the same colours throughout. Because we don't want to confuse people by showing, you know. If you want them to look at the form and you've got two sketches and ones done in my hand and ones done in someone else's hand, then that can be confusing.⁹³

JS: So that can confuse the clients?

EG: Yes. So really what we want them to concentrate on is the particular aspects of that sketch that are, if you like, different to say sketches two, three and four. So that, basically, the object of the sketch is so that you can get the client to agree with, agree on what are the most relevant, the most relevant features really.⁹⁴

JS: And at that client meeting you're talking about this area here? (Indicating gap in model of practice between concept and development design stages).

EG: Yes. And then we'd move on then. With a quick project, with a client we've got a good relationship with that would probably just be, we'd email them through and ask them for their feedback. And in the email, or sometimes in the design sheet, we would say which one we'd recommend.⁹⁵

JS: And that's then three or four different ideas represented in 'the same hand' using the same tools?

EG: Yes, a number of ideas. And then or sometimes that would be a face to face meeting where we can completely go through the different issues. Because often certain options have got certain ramifications that's going to effect the detailing stage. Even though we haven't detailed it we can say, well 'if you choose this we know that's probably going to be more expensive' or 'that's going to be more difficult to achieve' so we'd flag those things up on annotated sheets but often it's best to talk to people.⁹⁶

JS: During conceptual design, as well as the sketching, and the developing up the sketching using Photoshop, do you use any 3D here? May be it could be physical 3D, sketch models, foam models or it could be loose digital 3D. Do you use that?

EG: Yes, it's especially helpful for scale I would say.⁹⁷

JS: The sketch model making?

EG: Well, we don't do an enormous amount of foam model making or actual model making now because a lot of our clients, well one of our big clients is Transport for London, and those objects are sort of bus stops, bus shelters, station environments. So they're kind of difficult to mock-up [laughs]. But we get, while saying that, what we would do, once you've got a fair idea of. Say if you had like your preferred idea, you might spend a short amount of time, half an hour or an hour perhaps at the most, just drawing that up in 3D to really sort of reassure yourself that's not, in terms of scale it's going to work.⁹⁸

⁹² 05EG_Development

⁹³ 05EG_Development TOOLS Sketching

⁹⁴ 05EG_Development TOOLS Sketching

⁹⁵ 05EG_Development

⁹⁶ 05EG_Development and TOOLS

⁹⁷ 05EG_Development use of TOOL CAD

⁹⁸ 05EG_Development and use of CAD

JS: In digital 3D?

EG: Yes, yes. More usually. I mean with some of our other clients, where it's household goods, then yes we might produce those in foam. But still that's more for our purposes really. It's just a case of. Say for example you've got, say it's a bus stop. You know it's got to have a time table that's a certain size and you could do a beautiful sketch, but if that's not in the right proportion then when you actually do it in 3D, then it, you know, it might not look quite right. So it's that, and also I suppose some things we might, you might quickly do an elevation perhaps. So you might say quickly do it in Adobe Illustrator or something.⁹⁹

JS: Ok interesting. Now if we could go back a little and look again at these tools you're using. So sketching and then working sketches up with Photoshop, for example and perhaps a little 3D depending upon the project, could you just say a little more about what you think it is about the sketching as a tool during this conceptual design phase when your getting together with your colleges here and work through a number of design ideas. I know you talked about speed. Is there more to it that you can think of?

EG: Well yes, it's quick, virtually. So it's quick to communicate amongst ourselves. And when you show a sketch to a client it's quite useful because it doesn't look like the finish article. And that's important because it encourages them to have input. It shows that these are just ideas. So, whatever you're presenting, it's not definitive. It's not set in stone so it encourages them to comment upon it. I mean, some clients, some clients find that hard to deal with. They want to see the final thing straight away but you have to sort of go through the process. So it's good for that, kind of, interaction and feedback.¹⁰⁰

JS: So it showing less commitment would you say?

EG: Yes, well it encourages you to, to look at say the design features without getting confused by, say. If it was photo realistic you might be enchanted by the image. We don't want to enchant people particularly, by the image. We want to show them a nice sketch but we really want them to concentrate on what the variety of the features are so we can, then at the next stage, do something which is beautiful and sums up all of the aspirations.¹⁰¹

JS: So you wouldn't necessarily go into doing a 3D model here (indicating concept design stage on model of practice), like you say a slick shiny 3D model?

EG: No, I mean we might do very basic 3D models that we might show but again, we would try to keep it a little bit open ended. The thing is as well, you know, if you've got say five design ideas, doing five to assort of very high level is going to take you a very long time and there's a chance, there's always a chance that the clients will be like, 'Ok, ideas four and five no', discounted straight away. Three, two, some good ideas in there but number one is the best, you know. So, we don't want to spend all our time because then you come across as not being value for money. So that's why sketching, all the sort of conceptual CAD, if you like, sort of early stage can be good.¹⁰²

JS: What would you describe as conceptual CAD, what would you use for that?

EG: Well, we've sort of gone over to Solidworks now. That's not really what it's for, but again it comes down to how much time and effort you put into it really.

JS: So would you use that conceptual CAD as a replacement for sketching?

EG: We have done yes, we have done. It sort of depends really how open the brief is. I think that might be what determined it. If the brief is quite open then we'd probably, defiantly sketch because there might be too many variations that we could come up with to explore properly in CAD. But if, for example, the brief was fairly defined then, then I suppose you'd be more lightly to quickly move into CAD or

⁹⁹ 05EG_Use of Development and Concept TOOLS

¹⁰⁰ 05EG_TOOL Sketching

¹⁰¹ 05EG_Comparison TOOLS: Sketching and CAD

¹⁰² 05EG_Use of TOOL CAD in concept design

something like Illustrator. So you and we have in the past rendered things on illustrator. You might actually use CAD, as I do, if I know the proportions of the object I'll draw it roughly in CAD, as some sort of block model, and then print that out and then trace over it. So that you can get the proportions correct as well.¹⁰³

JS: It sound that there is something about sketching that makes it so useful and effective. You talked about the brief being nice and open, then you use sketching more than the loose CAD. Is it fair to say that there is some thing about sketching that courses you to think more openly or more laterally than CAD?

EG: Yes, of course. Defiantly, yes. The thing with CAD is that every decision is very specific. So with Solidworks every dimension you have to enter a figure for example. Obviously, when I draw a circle I don't have to decide that that's 50mm rad (sketching a circle in sketchbook). I don't have to decide that that's a 2 degree taper or whatever (continues to sketch a second drawing in sketchbook). Well I've drawn it but I think it would have taken me a bit longer in CAD. So I think it's time but yes you've got flexibility with thinking, because you've got time I suppose.¹⁰⁴

JS: Interesting. So could we move on from concept design stage going into development design, after the client meet you talked about here (indicating space between concept and detail design in model of practice). And then, what happens? You go into development design. Would you say you move away from sketching?

EG: Crickey, well no I suppose not. But again sketching will be used internally for deciding, for example, how. I suppose at that stage you're probably thinking about the different components that make up the final design. Or you're begin to get to grips with that, if you haven't already thought about it.¹⁰⁵

JS: You seem to be saying sketching is still used here in order to get it right in your own mind?

EG: Yes.

JS: The more detailed parts of the design.

EG: Yes but you'd be probably less lightly to show those sketches to the client.

JS: So these later sketches are made almost as, not exclusively, but more for yourself.

EG: Yes. That's the sort of sketches that are in this book (indicating detail and systems sketches from sketch book). These sorts of sketches (indicating assembly sketch in sketchbook). So like how two parts might fit together. So yes, beginning to detail it really. Perhaps that's jumping the gun a bit.¹⁰⁶

JS: And then so development design that's when you move into CAD proper or 3D CAD proper?

EG: Yes I would say you're beginning to start to nail that down. So moving in, using it at the right scale, starting to think about the different materials you've got.

JS: And you find CAD very useful for that, do you?

EG: Yes, of course.

JS: Do you use conventional model making techniques here at all? Do you have a workshop where you might construct appearance models?

EG: We have done but again, because a lot of the stuff we design is much larger scale. We don't get into it but then we've done some sort of accessories for mobile phones, like in car kits. We've done bread

¹⁰³ 05EG_CAD in Concept design

¹⁰⁴ 05EG_Comparison of TOOLS Sketching and CAD

¹⁰⁵ 05EG_TOOL sketching in Development Design

¹⁰⁶ 05EG_Use of TOOL Sketching in Development/Detail

makers and kettles and things like that. For those we'd be much more likely to do a clay model or a foam model or a card model.¹⁰⁷

JS: And that is, why do you feel that that is necessary? It may sound an obvious question, but why do you feel it's necessary to have a physical model, a physical embodiment of ideas if it's to be interacted with by the user?

EG: It's because you need to understand the human scale of the object. You know it's the touch. How does it feel when you pick it up? Does it have a handle? You know something's got a handle there. It's pretty important to test that out properly, not just on CAD. So yes, certainly anything that would involve, or furniture or something like that. That involved direct human contact or interaction then I think, yes physical models have got to be done at some point, certainly.¹⁰⁸

JS: So you're describing an inability to interact physically with the CAD representations.

ED: Yes, you can't pick it up.

JS: So you go into development design where you start using 3D CAD proper. And then you would have another client meeting somewhere along this continuum? (Indicating area in model of practice between development and detail design).

EG: I suppose the thing is this stage is slightly more difficult (indicating detail design) because its different projects work in different ways and different clients work in different ways. For example, with Transport for London. Now the way they work is we work directly for their design department. So probably at this stage here we're presenting to those guys (indicates concept design stage in model of practice) and they'll know design to a certain extent so they can interpret the sketches. But this is what has happened in a recent project. And then in terms of development what happened was we had to develop those ideas up so that they were photo-realistic and a series of elevations. So we were still using Photoshop but we were using, we used CAD basically to draw it at scale. Not detail all the insides for example, but being aware that this has got to go out to that size. So at that point you'd probably sort of sketch out you know (using the Dictaphone as an example) that's the profile, that's got to have a light in it, that sort of size, we need that sort of gap. And then you can sort of start to get the outside dimensions. Which we would then, then that was drawn in CAD and finally sort of finished off in Photoshop. And that was combined then with elevation views of it, which had the dimensions on it. And the purpose of doing that was so that they could then present that to the board of directors. I'm not sure where that comes with this process? (Indicating model of practice). But after that point, the sort of design was approved. And then we moved to detailing.¹⁰⁹

JS: So, generally speaking, there is this shift. Here (indicating development design) you seem to be saying you've gone from your initial sketches wide (concept design). Coming in slightly narrower here (development design), and then you started to detail up here and then perhaps go onto detail design. So this is the firming up of the detail? And then you move on up into...

EG: This stage is going to be where we are actually drawing everything to scale (indicating final stage in model of practice) if that's what's needed by the client. I mean some times what's needed by the client ends here (indicating detail design). They just give it to their manufacturer. So you resolve it. But like with Transport for London, they haven't got manufacturers themselves. So they need the full instruction so we take it this far (indicating final engineering stage in model of practice).¹¹⁰

JS: And the tools at this stage (indicating detail design) almost exclusively CAD?

EG: Yes, pretty much. But again the thing is, you'd probably still use sketching to. The thing about CAD is its very flexible but it's good to get it right first time. So you might work it out in your sketchpad, you

¹⁰⁷ 05EG_TOOL Conventional Model Making and Development

¹⁰⁸ 05EG_Use of Physical embodiment TOOLS at Development

¹⁰⁹ 05EG_TOOL Use at Detail design and rational

¹¹⁰ 05EG_Detail design and TOOL use

know the basic dimensions, not everything. I mean certainly if something's very complicated then doing it in sketch format could be quite worthwhile actually. Otherwise you could waste a lot of time on CAD.¹¹¹

JS: Why would you waste a lot of time on CAD? What is it about CAD that stops you from being able to do what you can do with sketching?

EG: With any CAD, I mean they all claim that it's adaptable, intuitive etcetera. But there still there has to be a process which you use. And the more you know at the beginning of that process about how its going to end up, the quicker and easier it's going to be to draw it on CAD. If you've got a total plank pallet you could spend a lot of time. So it's good to try to get as much of this sorted out before you draw it because there's different techniques for doing different features because if I was to draw this (picking up Dictaphone) there's a draft angle tool that could do that. Or maybe I would have extruded it from this side and then cut that off like that (again indicating angle on Dictaphone). And I know it sounds simple but there's a sort of knock on effect, how do I then do that bit? And so just thinking about it a little bit and you might want to sketch that out first.¹¹²

JS: And so that sketching aids that thinking process before you move onto, and during your use of CAD? And so you're working with sketching and CAD at the same time would you say?

EG: Yes, certainly when I'm working on dimensions. So I've got like, plans and dimensions so I know exactly what size it's going to be before I start. And then I can just refer back to that (indicating sketch in sketchbook). It's almost like a little blueprint to do the CAD by. But those sketches are for me only really. I mean, I might discuss them with some of the other team, but even that's not lightly.¹¹³

JS: So these sketches and some of your over sketches you'd say are for your own personal reflection on ideas. You sometime use sketches to communicate with yourself?

EG: Yes it's also handy for making a quick note as to how big something or large something is in the design. With CAD, you know if you want to interrogate the length of a part or something you have to select that part. You've got to select that tool and go in there and click that bit, and click that bit. And then it tells you. Great it's really accurate but if I've already written it down. I mean, 'oh yes it's that bit. So now I know that bit fits there; got to be that much smaller'. So I suppose the difference between sketching at this end and this end (indicating concept design and detail design on model of practice) is at the end it's more really personal to help you. I'm sure some people who just do CAD all the time, I bet they don't even bother with doing any sketching. I bet they're minds are so into the CAD. I quite imagine. Sort of part of the computer but I'm not. But at the early stage it's the sketches you would show to people. As it goes on, you wouldn't show those detail sketches to other people really.¹¹⁴

JS: So here (indicating concept design) you have sketching for communication and, obviously for yourself to work through your design ideas. Here (indicating detail design) this is predominantly sketching to help you in the finalisation of those ideas?

EG: Sketching is always; you can always use it to make a record of thoughts and to explore different ideas. And at this stage (indicating detail design) there might be different ideas for doing a connection detail or something, which the client generally doesn't hear about. That's not to say it's something hidden. But that sketching is just as important from the point of view of getting the design done. Because there could be three or four ways of attaching two pieces of metal together or what ever it is, or two bits of plastic clipping together. And that's going to be, and one could be very difficult to achieve. One could be very expensive to achieve. So it's good to sketch those out and then talk to a college or something, or the manufacturer. There's a lot of that as well, that's true. Often, if you're talking to manufacturers, sketches are very helpful at that point to.¹¹⁵

¹¹¹ 05EG_Rational for Detail TOOLS

¹¹² 05EG_TOOL CAD

¹¹³ 05EG_Simultaneous use of TOOL Sketching CAD

¹¹⁴ 05EG_Comparison of TOOLS Sketching and CAD

¹¹⁵ 05EG_TOOL Sketching plurality of use

JS: To get it clear in your own mind?

EG: No, No. Let's say we've got a manufacturer of aluminium tubing, for example. And they've been doing it for fifty years and they know all the best ways to weld parts of aluminium tubing together, and I'm not an expert on every possible manufacturing process there is but I know a lot, but, if you want to talk to these guys, and they're very, if they want to do the job. So they really want to be helpful, one way, whatever their name is, 'I've got an idea of how we connect these two pieces. Can I do you a sketch to show you?' Might usually fax it over or whatever. Or email it through and it just shows that quickly. Now you could draw it on CAD. And you could create a render. But the time it's taken me to just go right, 'that's the size of it', chuck on a few dimensions (drawing a talking sketch to illustrate point). And then those people might be, 'oh yes that's a good technique or you might want to think about a good technique we've been using lately'. Something like that. So that's probably at this end (indicating detail design stage in model of practice).¹¹⁶

JS: Can I asked you have you ever used the cintiqu graphics tablet?

EG: I haven't no it's. Some of the other guys in the office have.

JS: Do they still use it here?

EG: No not really. Not at work. It's some thing I'd like to get into. It's got a particular stylistic quality hasn't is? Which is good but also worries me a little bit I don't know.

JS: In what way does it worry you in its stylistic quality?

EG: I don't know the makes everything look sort of computerised, generic, samey. I'm not sure. I mean...

JS: Is there's something about hand sketching that is more personal, more personal to the designer?

EG: I think the reason people use these tablets is to create an effect that has a particular visual feel to it. That's not necessarily why we use sketches. We use sketches to help the designer move along the design process. So it's different aims really. So we don't necessarily want them at that point. If we've working closely with them and we've got their trust, we generally feel we don't need to wow them particularly with great imagery. Like that. A lot of them will ask for, further on they'll ask for a render which is photorealistic, for example. To get to that point you have to do the CAD. So that's quite far down the line. But that's probably where we would create something that wows them. So 'this is like exactly what you're going to get'. This stuff is good [cintiqu tablet] I admire it. But I, again, I think it's probably the time it takes to do that as well. You know, if the issue there was, I mean he's drawing a car (indicating image of cintiqu tablet in use on model of practice), but if the issue was what shape headlight shall we have? There might be quicker ways of doing it. Yes, I think that's probably the difference. We use sketching at the early stages to help are clients to move through the process, to make the dissensions. And then later on, once the decisions are in place, we would then make it look great.¹¹⁷

JS: I see, Interesting. Ok there's one last part to this and then we're finished. If you could think that you are going into a university to a graduate exhibition of their work or maybe New Designers, and perhaps you're there looking for a new graduate, what is some of the skill you look for first in the work of a graduate designer. What do you think is an important skill set for the graduate designers to have in terms of their ability to communicate through some of the tools we've been talking about?

EG: I think they need a basic understanding of nearly all of the tools we've talked about. I think that has to be part of it. The thing about when you're a junior is you might get asked to do anything. We, because we're a small consultancy we don't have people with specific roles because if the person with a specific role takes a holiday for a fortnight then no one else can cover what they've been doing. So we've all got, some of us might have, I'd be more adept at doing one thing then the other, but I think it's a range. So

¹¹⁶ 05EG_TOOL Sketching

¹¹⁷ 05EG_TOOL Digital Sketching

you need to be able to sketch. You need be able to communicate through sketching. And not just, sort of, kind of drawing beautiful cars. That's one that always comes up. You'll always see that one, somebody will but sketches in, rather than to explain their design thinking sort of like this is what I did on the weekend kind of sketch.¹¹⁸

JS: So that suggests again that a lot of the graduates are using tools in a different way than practice?

EG: It's almost like they're drawing a picture rather than using a sketch to communicate or explain an idea. And what's good as well is that, what's good to see when they're using sketches or CAD or whatever, to show that they don't just think in one particular way. That they are capable at looking at one product or one brief and coming up with a series of solutions and sketching can be good for that.¹¹⁹

JS: So sketching opens up their decision making process?

EG: It demonstrates that you can because sometimes what you might see is just like one beautiful CAD rendering at the end and then you think well, that is very nice, but how did you come to that decision to make it that colour, to make it that shape? Then if you see some sketches or some variations, then you can begin to assess whether that person has actually made some informed choices or whether they just went into their CAD package and drawn the most sexy looking thing they could.

JS: And that can impact their ability to think more laterally do you think? If that's what you're saying CAD, used in that way might be a constraint?

EG: Yes. But that's why you use it at the end when you've gone through that process of determining all the features, all the sizes already. So, I mean it's very tempting, I get tempted as well, unfortunately, to do CAD too early because I want to, I'm eager to see what it's going to look like really. And you have to some times stop your self and think 'hang on a minute I haven't really thought this one through properly yet'.¹²⁰

Perhaps what students' are less nuanced in doing, you decide you're concept but it might be a different radius. Just the slight variations you can explore with sketches can be quite important as well. So I suppose yes, obviously CAD is important as well. I mean sketching not the be all and end all, but it's the beginning, it's certainly a way to communicate easily. And for someone to demonstrate that they can communicate easily.¹²¹

JS: So they've also got to have the ability to use a CAD tool or CAD software?

EG: Yes, if we were to employ them yes.

JS: Some of the designers I've interviewed have said CAD is a tool you can learn. It can be taught. But that sketching might be in some way innate, or an ability to do well of not so well. Would you agree with that or disagree.

EG: I would probably agree. But the same could be said for the decision making process really that goes into it. I mean a lot of people can sketch some beautiful things but they might not have a logic behind them that makes sense to the client. So you, again, you've got to use it based on facts.¹²²

JS: Did you say you had a rapid prototyping machine?

EG: No we don't. We have, a lot of our clients get rapid prototypes done. We don't tend to do it on their behalf. There's so many of these companies around that they will inevitably come into contact. Especially as some of our clients are more manufacturers so they inevitable know the right people. So yes, because we do, because the end results is either 3D CAD, like an Igees file. Or 2D CAD drawing based on a 3D

¹¹⁸ 05EG_Skills Set

¹¹⁹ 05EG_TOOL Sketching

¹²⁰ 05EG_TOOL CAD

¹²¹ 05EG_Comparison: TOOLS Sketching CAD

¹²² 05EG_Comparison: TOOLS Sketching CAD

CAD, so we have a 3D CAD anyway, in most cases. So yes, so people do get rapid prototypes made and they can be pretty impressive. Very useful yes.¹²³

JS: Ok. That's all. Thank you very much again Ed.

EG: thank you, great.

Practitioner Interview: Pr06

Practitioner Interview	Pr06
Date/Time	Fri Nov 13 th 2009 12:50-13:40
Consultancy	xxxxxx Design Ltd
Interviewee	xxxx xxxxx (AD)
Position	Managing Director
Interviewer	James Self (JS)

JS: Ok so, first of all I'd just like to show you a model of the design process and get your opinion on what you think of this model. This is a model taken from some work by a number of design academics who have suggested a three stage approach to design practice (fig 1). Now, this shows five stages on the model, but it is these three core stages that I'm most interested in most because the literature suggests it's here that industrial designers use tools of embodiment to communicate, to help develop their design ideas. So I wonder if you could have a look at these stages and tell me what you think of this as a model of industrial design practice (indicating model: fig 1).

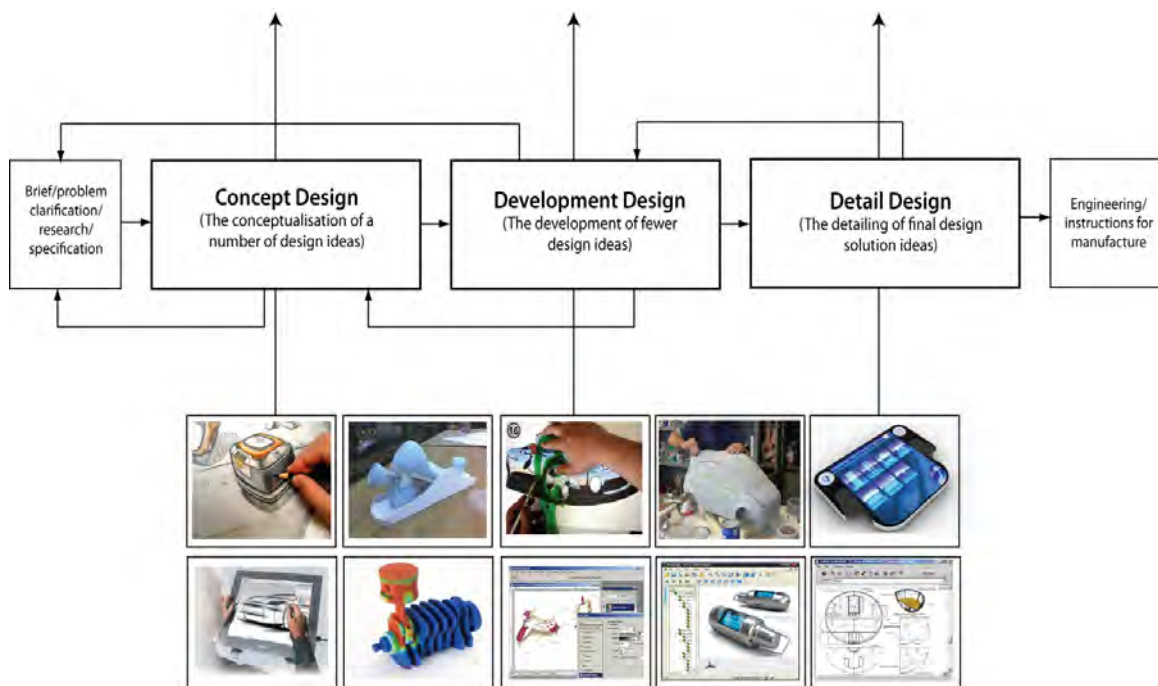


Figure 5: 3 Stage model of practice

AD: My first impression is yes, it's pretty much how we do things. One thing, looking at it, from concept design, through development design and detail design, often is, well we would merge that with stage 5, so

¹²³ 05EG_TOOL RP

you could, so the detailing of a design can't happen until the engineering. Engineering, the, the constraints, the realities of engineering a product, affect the detail design intrinsically. You can't get away from that. So I don't see how you can do the detail design prior to engineering to be honest (indicates detail design/engineering design on model of practice, fig 2). And yes, detail design. I guess it's just terminology, isn't it? That could be just final concept for approval, detail design. Normally we would term as engineering and final resolution of it.¹²⁴

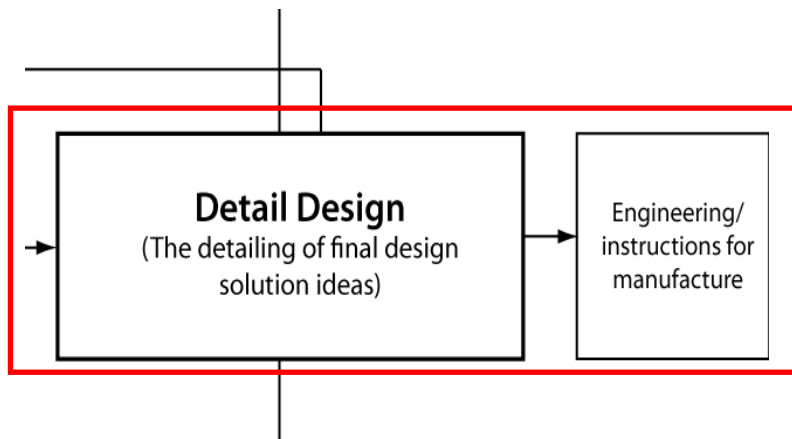


Figure 5: indicating interviewees concern for integration of detail design and engineering practice

JS: And these arrows suggest iteration between the stages, obviously. So there is iteration and um.

AD: Absolutely, yes.

JS: And I suppose, as you say, it depends as much on the design project as to the starting point? You may start here (indicating development design) or here (indicating concept design). But there is a general agreement that it funnels through from an open end, conceptual design, through to a more defined – detail design.

AD: Yes, it's just missing the link here, (indicates engineering for manufacture, fig 2) It needs an arrow back from engineering to detail design. I mean that could be well down the line of a project when technology changes or something else might well change. And it will then affect the detail design of the concept. You can't avoid that. Again, to maintain any original design intent, you can't sign off there (indicates detail design stage, fig 1), which this model says it has. The design, the industrial product design element has signed off here and that's simply not the case a lot of the time.¹²⁵

JS: Ok interesting. As I say, the research that I'm involved in is looking at these three stages of design practice; concept, development and detail design and the way design might funnel through these three stages and the way that industrial designers use these tools and processes in order to support the communication of their own intentionality; to themselves and to others. So I'll just, the next few questions will be asking you about the different tools you use during conceptual, development and detail design. So, Could you say what tools you use most often during this conceptual phase of design practice? What tool or tools would you use most often?

AD: Yes, well we're still, you know, it its development of initial sketches, again, it depends upon what the client wants. Sometimes they want to be involved sometimes they don't. So, were a client wants to be involved, there's an interim meeting. So, prior to any concept presentation, it would be rough sketches, initial ideas. We'd use 2D CAD, again so you've got a feel of proportion and scale, without going into the third dimension, which then can start clocking up more time. Although that said, using a 2D Illustrator,

¹²⁴ 06AD_Process

¹²⁵ 06AD_Process

Photoshop type package¹²⁶ can take longer to get visually to represent what you've got in your head down on paper. Can take longer then actually creating it in 3D and doing simple, preliminary render, but you do get that danger, if you show. We've been bitten before by showing things to raw in sketch stage, where the client just doesn't get it. If the client is familiar with seeing the 3D CAD, they want that right at the early start of the process. The flip side of that is if you show them CAD too early they think that's it there's no development to do. They think the jobs done. What are doing over the next two stages? Because we've shown it all up front. They have a problem in seeing that that is just a three dimensional virtual sketch. It is, it's a bit like showing, a sales and marketing team, we maybe skipping a stage here but, showing a sales and marketing team a final block, they think that's it, put it in a box and we'll sell it. And that can be kind of dangerous, as you know with model making.¹²⁷

JS: So my next question was asking about the effectiveness of the tool's you've suggested for concept design; the 2D CAD and sketching. And I think you've, kind of started to answer this. Are you also talking about speed?

AD: Speed, it allows the client to engage. The client can see the client can contribute. So they have that, sort of contribution, that feeling of ownership over any ideas. It becomes a collaborative stage of a project. Again, we find that, I suppose it's done to how you work and it depends on the client themselves. The client might just want, 'why are we contributing, we're paying you to do that' if they've got that approach. Or, mostly, they want to be involved. They want to partake. So the sketch stage, where it is a more informal around the table. You know we wouldn't, we'd probably present sketches on screen just so you can retain their attention to one focus, as in within the display. But then you would have all the raw sketches out so that it is round the table, scribbled on, crossed on, you know, notes are added. There the collaboration helps. And that is if you have the luxury of a round the table discussion and it's not a virtual meeting or anything else. But...¹²⁸

JS: So you would show those raw sketches you'd have that as part of your communication to the clients at the initial stages if that's what they wanted?

AD: Well, yes. I mean yes. As I say we have been bitten before where we've shown that and they've expected to see 3D. And they can't compare the two. And it's almost they'd look at a sketch and think well, 'why are you showing us a sketch, usually it should be more finished?' So again it depends on the client's expectations as well and the client's budgets. As long as it's clear in a project document and a proposal to them, that it's deliverable, suits their budget and their expectations, so there are no surprises. I suppose that's where we've learnt from either showing a too raw a presentation or going in too finished. If you go in too finished it can be detrimental as well. And there's never a happy, it's always a balance.¹²⁹

JS: So maybe sketching, possibly, more towards the more not finished enough, can be a problem with the sketching. 3D modelling, the way that that media communicates can present problems with too higher Level of Commitment?

AD: Yes. It's a bit. A 3D rendering, it can look like you've, that's your final, although it's just a sketch, it can look like that's your final take on a project. And if then they start saying, 'yes, but, that component's not going to fit in there'. But you wouldn't have that argument with a sketch. Because, although the two, you could argue, were equally well or not so well resolved, the fact that they are communicated differently, people's reaction is different.¹³⁰

JS: So that's the way you use these concept tools to communicate with others. What about yourself? Do you think you might also be affected in this way, the way that you look at the 3D render your working with and that influences you as apposed to using sketching as the medium of embodiment?

¹²⁶ Two commonly used digital graphic manipulation tools used within industrial design practice. Photoshop and Illustrator are part of the ADOBE suit of software.

¹²⁷ 06AD_TOOLS used at Concept Design

¹²⁸ 06AD_TOOLS Used Concept Design

¹²⁹ 06AD_TOOLS used Development Design: Sketching

¹³⁰ 06AD_TOOL Sketching

AD: I mean there is a danger in that yes. I mean anyone can, you know, dress up a bad idea on CAD and make it look good. But you've got to have that ability to see through a very snazzy, zippy render and actually question, not good design, you know? And there are too many students that all come out being able to do 3D renders but the design itself is horrible, you know? It's just not, it's either not relevant or it's clunky or it's just not been thought through. And I think the thinking through of any design work is, I would argue, it's a combination of both, but is at that sketch stage. It's understanding what that project, what that new product should be. And when going straight onto CAD I don't see how people, people probably do but, personally, we don't.¹³¹

JS: What you're saying is sketching and CAD affords different ways of embodying your design ideas and if you're using, you've got to be aware of the affordance and constraints of the media of CAD? As apposed to sketching and the way that you're using CAD can, would you say it can, for example, crystallize your design ideas too soon.

AD: Oh defiantly, an absolute danger. I see it in the students that go straight onto CAD. They'll never go back to the beginning of a, like you would with a sketch. You can quite easily flick through a sketch and think; I'll go back to that. If they started building something in CAD it will almost force it to work because of the labour that's gone in up to that point. Now, the realities are I suppose, I see it as a positive, if you want to look at it from a positive perspective, and I don't use CAD very much at all. From a professional point of view, I use CAD people as part of our company. I've got a CAD specialist who translates my thinking from sketches, however raw they may be, and 2D elevation views to get dimensions. I'm not, weather it's encumbered or inhibited, by my CAD abilities, at all. I put that all on my CAD technician (laughs). I have to say sorry to him. But, I'm not, you know, if I was to be modelling something and presenting something with my CAD abilities, totally driven by that, I couldn't do it! So I'm freed up. So that's what I believe the product should be; someone else's problem to generate that in CAD. And that's the real danger, people who are designing stuff to their abilities or their software's limitations...¹³²

JS: I see, and it sounds to me that if you're, the ability to use CAD is learnt in a slightly different way then the ability to sketch? Do we learn how to sketch we can develop our sketching; we can be a better model makers, thinking back to sketch model making? CAD is a different process would you say? CAD is a different process, would you say?

AD: Yes

JS: You are learning this software or this software or this software.

AD: I think exactly that, yes, yes. I mean it does have, it's less about a designing process, a designer's way of working. Like you say, a designer is either sketching or making rough prototypes or models to help his own creative process. Once you start getting into the realities of proper tolerances and making surfaces meet, suddenly that creative side is gone all, you know, geometry, technique; it's a different part of the brain if you ask me. And I'd quite happily leave that to someone that enjoys that side of things. Now weather there's a, I'm missing a package that allows us to virtually create something.¹³³

JS: That is more intuitive?

AD: Yes, I mean, that's obviously where it's going with the sketch tablets and everything else.

JS: I was going to ask you do you use the sketch tablet, like the Wacom cintique?

AD: No, it's one of those things that's on the list of must do because I can see, you know, when you start doing sketches and you've got to go and do, that's not as good as I wanted, you go into Photoshop. You try and dress it up a bit in Photoshop. You're almost veering into that...It is it's a tool. To dress up what might be a poor sketch to something that gives the flavour or zing that you want then client to see in your vision. And if the tablets can take out a few steps of scanning and Photoshopping and you can use those

¹³¹ 06AD_Comparison of Sketching and CAD

¹³² 06AD_

¹³³ 06AD_TOOLS Support of practice: Concept to Detail TOOLS

tools more effectively. Defiantly, that, for me, would be great. Again, it's one of those things to invest resource and time into.¹³⁴

JS: So could the tablet be seen as a learnt tool as well, in the same way you have to invest a certain amount of time in order to learn the interface?

AD: Yes, but it's like sketching. No ones a born sketcher. It comes from a confidence doesn't it? And even if your sketching style isn't, you know, Leonard Davichi, it needs to communicate. And I think that's were the sketch tablet could be, you know, this nice marriage, defiantly. I mean I envy those that can use them because it is a skill but there's no denying the fact that there needs to be an artistic skill. If you haven't got an artistic skill I don't think you can use a sketch tablet and pretend that you have. It is coming from the hand. Where as the CAD packages, you get the top-end, you know, Alias package people that might have no idea about design! But, if they're guided right, then they create the most fantastic, you know, ink glass surfaces and everything else that a probably designer wouldn't to. I think they're different beasts. That's the right word.¹³⁵

JS: Ok very interesting thank you. So moving on from concept to development, where your, other designers have talked about client meet where they're present three or more and then they'll go into development design to develop three options or two options or maybe just one option, depending on the budget, the size and the job.

AD: Yes

JS: And during development design then you move into 3D proper?

AD: Yea

JS: And this is where, in your case, you pass your conceptual design ideas to your CAD specialist?

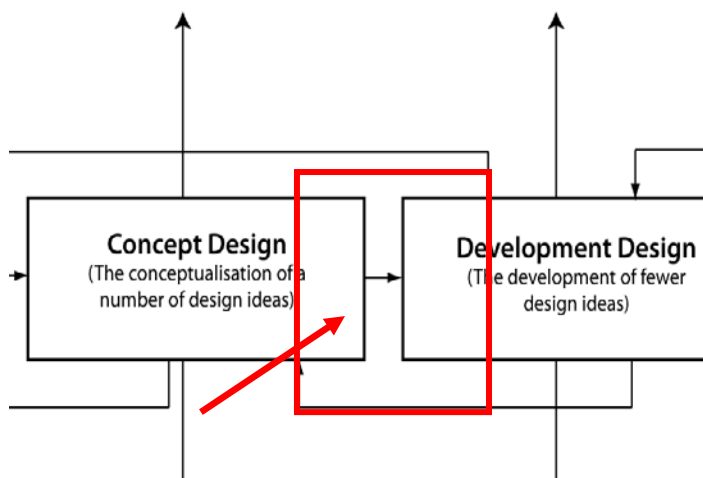


Figure 6: interviewee indicates boundary between concept and development design

AD: Yes. The client would get involved and we'd get the realities of the components and suddenly then I'd get a few more phone calls and needing more information from them. Because that is where it starts to become virtual reality. So, yes. I mean normally it's quite a, the concept stage, if you like, we'd often go into a certain amount of 2D work. So, there's no point in showing, you don't want to come unstuck in showing a sketch of an idea that actually isn't feasible. Because if you've had that meeting there (indicating boundary between concept and development design, fig 3) to sign off, or take two, three

¹³⁴ 06AD_TOOL Digital Sketching

¹³⁵ 06AD_Comparison of TOOLS Sketching and CAD

preferred routes forward, as designers, you don't want to be entering a second stage work that, actually, can't be delivered because of the sketch you did. First off, so, the sketches have got to have that element of scale on reality to it anyways. It's the designer's role. So you want to ensure anything you've shown in this first stage, (indicating concept design stage, fig 3) can be progressed because, then you face from a design point of view, the client saying then, 'why can't we move that forward!' The sketch was completely, you know, made up! So there has to be that reality in there. That's where components start moving into it. Although we're not talking engineering and detail design yet. We're talking about tightening up, so to speak.¹³⁶

JS: And for these tightening-up tools this is where you'd bring in the 3D, what 3D CAD software do you use?

AD: We use Solidworks¹³⁷.

JS: But, as you said, you don't do that. But I was just wondering about your relationship with the people who do that for you? How do you...

AD: We're like an old married couple. Well, I've worked with him for sixteen years. So, what, you know, it's a minimal amount of translation. He kind of knows what I want, a lot of the time. It is a bit like that once you find the right people to do that side of things. Yes, I feel a bit exposed. I should be giving him more, almost, preliminary CAD data from my end to help fast track his involvement, but I'm quite happy not doing that. I do feel that you see people that are, you know, CAD jockeys, CAD monkeys, whatever you want to refer to them as. But, their designs are based around their CAD ability. And I don't think that should be the case. But then that's my own justification for not being skilled at it (laughs).¹³⁸

JS: Their own CAD ability, yes.

AD: You can see it in a lot of design houses. You know you can almost look at some design house and see what software they're running, you know?¹³⁹

JS: Yes?

AD: You look at companies that have got all the very organic surfaces stuff, they're not using Solidworks. I bet they're on Alia or, you know, Rhino, they've got, you know...¹⁴⁰

JS: It's very interesting. The digital software they use...

AD: Or just the skills they have in house...

JS: Influencing the, kind of, fundamentally the form of their design

AD: Yes, yes, I think so, yes. Like I say if I was doing, if I was having to CAD model, everything I'd be, you know, square with a round hole, a round button because that's my abilities with CAD. Whereas, actually, it shouldn't be about that. It should be what's right for the project and the product.¹⁴¹

JS: We've talked about sketching, 2D CAD, 3D CAD, moving into CAD, moving into Solidworks more, defining the designs in more detail during development design. But, do you use any kind of physical design embodiments so, some foam sketch models, card sketch models, do you have a workshop where you go in and this kind of thing where you're working with workshop tools and processes?

¹³⁶ 06AD_From Concept to Development design and TOOLS

¹³⁷ SolidWorks is a 3D mechanical CAD (computer-aided design) program that runs on Microsoft Windows and was developed by Dassault Systèmes SolidWorks Corp (Wikipedia)

¹³⁸ 06AD_TOOL CAD

¹³⁹ 06AD_TOOL CAD

¹⁴⁰ 06AD_TOOL CAD

¹⁴¹ 06AD_TOOL CAD

AD: That's right. From a designer's perspective it's that sort of proving out of a sketch really. It's to make sure that what you are showing is achievable in terms of the scale, proof of principle rigs. Things like that. All play a part in those first two stages (indicates concept and development design, fig 1). You know, weather we're then using card templates, from a designer's point of view, from 2D work, just to block out, you know, mock space models. To then, using preliminary CAD data, just to have it milled in a block or a simple SLAs or things like that. Even at that stage (indicating development design, fig 1) once you've started creating the 3D data you'd be crazy not to use that as part of the model at development.¹⁴²

JS: Do you have any in house 3D print ability or RP machines? Or do you send it away?

AD: Yes, send it away every time. The hand stuff we'd do obviously, but the rest we send away.

JS: How would you say that impacts your design practice, or not. What is the, can you compare and contrast the process of hand modelling and getting it sent away and having it back? Do you get it 3D printed, look at it test it; go back to the CAD data. Then another 3D print. Does it work like that?

AD: Yes, I think we've found in the past. I mean before, when SLA's and things were, were much more expensive, you became much more precious about data going out and wanting it to be right first time. I think, now days, we're much more, you know, instead of being so focused on trying to get it right the first time. You think, well, 'I could spend a week going round the houses and wondering a bit more, how it's going to be right after a week. Rather than just saying press the button go. That comes back. Then you've got something to make an informed decision on. Rather than it, I suppose, be coming from the craft side, the designers side. Trying to get it right first. I think there's a bit, there's a more instant using of 3D rapid prototyping output as a rough proving out part of the process. And that's because the costs have come down, the speed at which it can be done. Just less precious about it now. You know.¹⁴³

JS: So most of your projects you would say you do use three dimensional representations?

AD: Not all, again, it depends on the budgets. A lot of the clients will fast track it now. We're constantly fighting battle to bring models back. They'll think because they've got a virtual representation of it now, we're home and dry. And it's sent out to china. Then the trouble starts if it's not what they envisaged.¹⁴⁴

JS: So they don't see the need for the physical embodiment and you seem to be suggesting there is an important of the physical to communicate?

AD: They know, actually, the model making time, in terms of, to create an electronic product as a block model, even if it's SLA'd with sprayed finishes and false screens and stuff, that can take so much longer, that can take half what they might have as a tooling time. And if its three weeks of model making, its three weeks off their project. But we are constantly fighting that battle that you need that sigh-off. A physical benchmark product because, as you know, a model can be better than the real thing, often is. Because a model maker does such as good job, its better then the end product. We would always have that with our models that it has to be better than the real thing. But then that becomes a benchmark which is more important now, with a far-eastern manufacturer. That they understand what they've got to deliver. Which, virtually, they can do, they can do what ever they want, 'ow right we spent about an hour, we got it off the tool here and there's injection marks on it here. Well, actually no, you need that physical model to say how much of its visible where. And, like you say, clients to touch and feel.

JS: Ok, so moving through development design into this detail design for manufacture, how deeply into the engineering process do you go? Is there a handover or is it now coming to a stage where you have an intermit relationship with the engineers and you see the project all the way through.

AD: depends on the customer, totally yes. I lot of it, you know, even if the customers are doing it their, probably clients and things are manufacturing partners in the far-east. You know, they're set up better then we are over here. But in terms of our data that goes to them, we have to insure that we minimise that loss of translation, if you like. So the data has to be good in terms of, you know, they start putting in extra

¹⁴² 06AD_Use of Physical TOOLS in Development Detail design

¹⁴³ 06AD_TOOLS RP 3D Printing

¹⁴⁴ 06AD_Use of TOOLS: Models Prototypes

draft here and there, things start getting bigger or thicker, we've allowed for it. We've, you know, that's why; as a consultancy with an engineer within, it's making sure that original design intent is maintained. That's why, you know if you were to just do a sketch and a quick foam model, and, sort of, preliminary CAD data from a non-engineering perspective, what might actually get manufactured, if you went from that data, could be totally different. Which is where you bring in that engineering aspect? It does help firm things up.¹⁴⁵

JS: With the engineering aspect, perhaps you're creating GA etc. Are you still using Solidworks for that?

AD: Yes, still using Solidworks. But we'd often do 2D drawings as well. So its 3D data. Fully dimensioned, 2D checking drawings as well. That, by way of, that sort of helps companies with bill of materials and the, sort of, systems that they have in place. But, again, it's to avoid a loss of translation in terms of the data. Its fine just sending a file but you need that reference in terms of notes, projection points, all that as 2D document we find very valuable still. And maybe that's because my design partner, if you like, has come from an engineering and technique draftsman background, so he always likes to create that sort of, that's his sort of, otherwise what's he got to show for himself?

JS: So what you're saying, it's valuable for himself as well. So, as you're coming to the finals of the design you're still designing here as well (indicates detail design, fig 1).

AD: Yes, we can still come back as well. If they say actually we can't do that. Can we change this? That's why this is...needs that link back.

JS: There is one last question here then we're finished. So thinking in terms of visualisation and modelling ability, what do you look for in a graduate's portfolio when considering them for employment? Let's say you're at young designers, what are you looking for in the skills set of a graduate designer? With particular reference to their ability to use tools.

AD: It's an awareness of what, a suppose, with the software packages now like Hypershops¹⁴⁶, things like that, you know, even I can render a 3D model. That's saying something. Its just drag and drop. But, that said, you know, you still need to have an awareness of what if that texture, what would work. It's a design awareness. It's not about, necessarily, software skills, I don't think. To me if they've got a good understanding of, you know, 2D Photoshop and Illustrator there're the standard packages that are used day in and day out as part of the process of laying out presentations and things like that. It would be very hard work taking on someone who couldn't use those. You know, you would have thought to put a portfolio together its standard. 3D package wise, it's a plus if they've got it but we haven't got, personally, loads of empty machines sitting round the studio waiting for people to do lots of wizzy 3D renderings. It's more about getting the idea right.¹⁴⁷

JS: So getting the idea, this design awareness, how do, what do you look for. Well obviously you talk to them and that helps. What else?

AD: They've got to be the right people haven't they. Your not...when employing anyone, you've got to have the chemistry with that person. If they're annoying, no mater how great they are with the software, I wouldn't have them anywhere near me because it's my working day.¹⁴⁸

JS: And sketching?

AD: Yes, absolutely sketching. And it doesn't have to be, necessarily great sketching. Great sketching is something I'd love to have myself. But it's to be able to, not being hesitant to sketch, um. We've had that over the years here [Kingston University, undergraduate product design course]. People aren't confident

¹⁴⁵ 06AD_Detail Design and TOOLS

¹⁴⁶ Hypershot is an emergent real time rendering software design to allow the intuitive rendering of 3D models without having to learn the affordances and constraints of the tool, as with other rendering software tools.

¹⁴⁷ 06AD_Skills Set

¹⁴⁸ 06AD_Skills Set

with their sketching and they won't do it. But look at any good designer their sketching's bloody terrible anyway. It's more about just communicating the idea to the next process.¹⁴⁹

JS: So using sketching as a conceptual tool and not be too precious about it?

AD: Yes that's exactly right. I mean that's what we have with students here (Kingston University). They'll do a little thumbnail sketch and they'll think that's the design. I've done it. But actually that's just the idea. And the sketching, no matter how bad you are, it's only by doing more and more of it you will develop your thinking. Develop that idea, and I think too often they're straight onto the CAD to get that final. Because they don't want to do a marker rendering anymore because you don't have to. That used to be how you presented the work. Not the case anymore. It's sometimes nice to see a marker rendering now. That's where the tablet type stuff, I think, cross those boundaries. Just that these people that have invested the tablet time. I can't wait to. I'm worried that if I start using it, I can't get the results in my head that I think I'm going to, you know; I'll be able to create those beautiful automotive renderings. That comes after years doesn't it? And you still have to have the hand, the hand skills still.¹⁵⁰

JS: Something about the hand that shows the, the use of 3D software doesn't show as much the individuality of the designer. There's something about the hand that brings this out?

AD: Yes personality. My business partner, as I say being a design draftsman, he gets a real; he came from drawing tractor parts on big A0 drawing boards where you saw that as a pencil drawing. It was a piece of art. You know how it was layer out. How I was dimensioned. How it was bordered and how neat it was. You could see a lot about the person that created that. That's all gone in CAD. And that's what's missing. Which you know, the tablet side of thing comes back in. Personality can come across. And I think, that's why you say when you're looking for a graduate, you're looking for someone with that personality, you know. Eighty percent of the students that will go out of colleges will all have that Photoshoped portfolio. Where the, you know, line art of hands holding things and. Well, where's the personality? What's going to be someone else's take? The flavour they can bring that's their own to it. It used to be in the sketching.¹⁵¹

JA: Thank you Andy. That was very useful. Thank you.

Practitioner Interview: Pr07

Practitioner Interview	Pr07
Date/Time	Mon Nov 16 th 2009 14:00-14:50
Consultancy	xxxxxx
Interviewee	xxxx xxxxx (AC)
Position	Director
Interviewer	James Self (JS)

JS: Ok. I'll start off by showing you a model of the industrial design process,

AC: OK.

JS: Of industrial design practice. This is a model based on models taken from academic and practitioners that have written about the process of design practice and it consists of five stages. Moving from the identification of a brief, to concept design, development design, detail design. And then off into

¹⁴⁹ 06AD_Skills Set and Sketching

¹⁵⁰ 06AD_TOOL CAD and Sketching

¹⁵¹ 06AD_TOOL Sketching

manufacture and specification. For the manufacture of the artefact. What I'm interested in is these three areas of the process. So concept, development and detail design. Particularly I'm interested in the way that industrial designers will use a variety of different tools and processes to represent and embody their design ideas. But, could you look at the model and give me your reactions to that (indicates model of process fig 1)? In your experience as an industrial designer, do you think that's a reasonable model of industrial design practice? So an open conceptual design stage moves into a more constrained detail design stage. And here (indicating border between concept and development design on mode, fig 1) you may have client meets or presentations of some kind?

AC: Yes, yep. Yes on first glance it certainly does. Yes, it does. Um, it's, important you have that arrow there; going from concept to brief (indicates iteration between brief and concept design: fig 1). In my experience I've had that where we've been briefed to come up with some concepts and then that's gone back in structured, or restructured the brief, as such. Um, so that's quite key I think for me. As I say from my experience. Um, yes on first glance that seems pretty much what happens.¹⁵²

JS: So, given this model of practice, I'm going to be talking about conceptual design then development design and detail design. And I'll ask you a little bit about the different design tools you use to support these three stages in practice.

AC: Sorry, just something more I'd like to say about this (indicating model of practice).

JS: That's OK.

AC: Some times, the only thing I could add to this is that sometimes the instructions for manufacture are you have them in mind very early on so that almost might sometimes start in the concept design stage because, I did a lot of work on medical products so the components were tiny. They were very small, very precise. So, when you're dealing with mouldings that small, even if you are coming up with a concept design for a mechanism, you always have to keep in your mind these bits have to be made. So, there's an element of sometimes, not in every project, but you have that (indicates design for manufacture) running alongside the top of these (indicates space above concept, development and detail design stages). Rather than being tagged on at the end.¹⁵³

JS: So what you're saying is you're conceptualisation of design ideas is also influenced by some constraints, which where always in your mind? And that these come from the back end of practice (fig 2 one illustrates this point)?

AC: Yes, yep. Just because, with plastics moulding, we always have to consider that the plastic had to come out of the mould. So even if you're sketching something on paper as a concept, you would then refine that sketch to just double check with yourself really that this could be moulded and you weren't designing an impossible piece.¹⁵⁴

JS: Ok interesting. Now, talking about the conceptual design stage at the front end of practice, could you say what tool or tools you use most during your conceptual design work in order to embody and communicate design ideas?

AC: Sketching, without a doubt and 3D CAD. And that would be ¹⁵⁵Solidworks. Sometimes, um, sketch modelling. Just rough, making something, seeing if you can make a rough working prototype to prove a particular concept.¹⁵⁶

JS: From foam or Styrofoam or card?

AC: Yes, that kind of sheets of plastic, yep, paper card.

¹⁵² 07AC_Process

¹⁵³ 07AC_Process

¹⁵⁴ 07AC_Process

¹⁵⁵ Solidworks: A commercial standard solid modelling software. Developed by Dassault Systemes Solidworks Corp, France, Solidworks is widely used throughout industry.

¹⁵⁶ 07AC_Concept TOOLS

JS: So, given these tools; sketching and 3D CAD and sketch modelling, could you talk about the reasons why these tools are most effective for you as a designer at the conceptual design stage? Why did you use sketching often and sketch models? In order to embody your design ideas?

AC: I guess, predominantly speed. Sketching is just very fast, you can get a number of ideas down very quickly. Um, because we, myself and my college, became very proficient in, in CAD, that became very fast as well. So we know we could start, once we had a certain confidence level, we got an idea of where we were going with an idea. We could pretty quickly CAD something up and it would be on screen. And then you could start to scrutinise the concepts, on a big screen rather than on a sheet of paper. That gave you more freedom to see things in a three dimensional sense rather than two dimensional. So it would be speed. And I think also, um, it just allowed you to communicate an idea very quickly to a colleague or to a client who might be by your side. So I think its portraying that idea in a visual way.¹⁵⁷

JS: Ok, just going back to what you said about this idea of a confidence level. You said you needed a certain confidence level in order then to move to CAD. Is that right then to clarify?

AC: Yes, it's a bit misleading. Um, sometimes, fifty-fifty, sometimes that would be the case you'd start off on paper then CAD. Other times we would immediately go onto the CAD, but that depended on the brief actually. If the brief was very well defined then we would go straight for the CAD. If the brief was a bit more fluffy, they'd be more inclination to start sketching rather than cadding anything up.¹⁵⁸

JS: And those initial CADs they were; what was that a loose 3D¹⁵⁹?

AC: Yes, yep a loose 3D.

JS: And these sketch models, styrofoam model. In what ways did the embodiment of ideas using the physical models help support your conceptualisation of ideas?

AC: Well some times we'd remember a mechanism. For example, my boss once remembered a kind of...it was a piece of plastic which you pushed down. And it used a rib on the underside to then lift up the lever. And he kept describing it and, you know, he was sketching it and, you know, I understood it but he, you know, it was too words. And he realised if you just got a few bits of plastic, you could just show, you know, the client and get the points across very quickly. So in instances like that we thought I could just quickly demonstrate this in five seconds just by mocking up some plastic and some card we'd make something. Just because it would be quicker then explaining it to a client, particularly over the phone. Our clients were sometimes in another country. So, you know, over the phone just wasn't ideal. But if we had a sketch model we could then photograph it in a couple of steps to kind of show any mechanism and say this is our starting point. This is what we're thinking.¹⁶⁰

JS: So with these conceptual design tools you're talking about their ability to communicate with the other; with the client. Um, in order to get your design ideas across to the client. What about sketching and 3D CAD and sketch modelling? The use of it to communicate and develop design ideas for yourself? Could you talk a little bit more about that? The way you may use these concept tools to reflect upon these design ideas? The affordance of sketching and 3D CAD?

AC: We'd often have a problem with a design. So, for example, we design a lot of medical injection pens. So they'd be they'd be a few components in the whole mechanism which weren't quite functioning as we thought they would. So we'd have to go back to the drawing board almost and re-design parts of or part of the mechanism. And it's a small part but it's an integral part. So we would sketch sometimes for days to try and come up with a different, you know, a range of configuration of components. It took, it had to be on paper rather than CAD because, we, we just weren't sure how to do it. And I remember one project in particular we had to switch the direction of the pushing force in a spring. Completely, um, sorry I'm explaining this really badly...Essentially we had to revere the way some components were working. They

¹⁵⁷ 07AC_Concept TOOLS

¹⁵⁸ 07AC_Concept to Development design and use of TOOLS

¹⁵⁹ Term borrowed from interview 03, Tan Tran, Alloy design

¹⁶⁰ 07AC_TOOLS Sketch modelling

were pushing one we and we had to switch them pushing the other way. And there was no point doing it on CAD because it just wouldn't have been useful enough to us. We had to go back to sketching draw sections, draw different sections, you know, from the X axis; from the Y axis. Then it was through that that we could then generate discussions with the team of the three of us. To then have the confidence to try and CAD something up.¹⁶¹

JS: So, there it sounds like you might be describing a necessary starting point. You have to be at a certain starting point, in your experience, in order to then progress the idea with CAD?

AC: Yes.

JS: There is some thing about CAD that just not; you can't use it before that point?

AC: No, CAD's fast when you know what you're doing. The problem was we didn't know exactly what we were doing to fix the problem. And because we didn't know what we were doing, we could have been cadding for the sake of just, you know, because we had the CAD system there. With the sketching, if we didn't know what we were doing, but it was just a faster turnaround of ideas. It just flowed better. I think that the CAD it would have been more constricting because you would have spent so much time designing the components, going down a particular route, designing the components in a particular way. Maybe it would have been a hindrance rather than an aid because you were kind of then in a certain pattern of thinking. I think with the sketching you were more open to different; you might suddenly get an idea if you were to quickly doodle something in the corner of your sheet. Whereas with CAD you'd have to start from almost from scratch. So I think it was a time thing as well.¹⁶²

JS: So, in your view, that pattern of thinking, that openness, in your view, comes from, um, the sketching's affordance. Sketching allows a different way of thinking openness and you talked about speed?

AC: Because um, you can have, you know, three, four, five different ways of trying to answer the same problem with sketching. I think with CAD the danger is that...particularly if you're not quite sure how to solve the problem; you might get stuck in a particular way of doing it. And if it's the wrong way, you just have to start again. And that's just, you know, very wasteful on time I think.¹⁶³

JS: Ok, moving long from conceptual design to development design (indicates the development design stage in practice, fig 1) you've gone through concept design using sketching, loose 3D CAD and, to some extent, sketch modelling. You have now moved into development design, what tools would you start to use to support your practice during development design?

AC: That would be CAD.

JS: Sure. Would you bring in rapid prototyping, 3D printing; other forms of physical embodiments at this stage?

AC: Not really. Um, perhaps towards the end maybe. So it was almost a stage between development design and detail design. Development was mostly on CAD, and that was um, it was actually...when you started to infringe on detail we get rapid prototypes made and start to see things click together, fitted and worked, within reason. Because rapid prototypes were quite, inherently limiting, Um, so yes we'd use rapid prototyping towards the end of development and the beginning of detail design stage. But for the development designing it would be mostly computer aided design.¹⁶⁴

JS: And, thinking about your use of 3D CAD using development design, was it Solidworks?

AC: Yes it was.

¹⁶¹ 07AC_Comparison of TOOLS: Sketching and CAD

¹⁶² 07AC_Comparison of TOOLS: Sketching and CAD

¹⁶³ 07AC_Comparison of TOOLS: Sketching and CAD

¹⁶⁴ 07AC_TOOLS CAD and RP in Process

JS: What was it about that particular tool, the 3D CAD tool, that made it more useful at this stage in practice (indicates development design fig1) than perhaps, you were talking about conceptual design and not being able to use CAD in certain situations. What was it about CAD that made it more useful when you moved into development design?

AC: Um, it just gave you multiple views of a design. You could section a model in any axis, at any angle. You could hide components. You could show components. You could isolate a sub-assembly with in assembly. It just allowed you to really get into the design at a much deeper level and you could just double check and go over. So every, every aspect of it. Did the teeth on one component mesh into the void of another component? Um, if those teeth, you know, as you twisted the component, did they have a suitable enough angle to ride up the corresponding component? It was just that Level of Detail that you could really, um, go in, develop and analyse the design much, much closer than you ever could with another tool I think.¹⁶⁵

JS: Just moving back a little, did you ever use, some designers have talked about hybrid tools. They would use their sketching and scan that into the computer and use, you know, Photoshop or illustrator to dust-up and tighten their sketching and then present those to clients. Do you use hybrid tools in that way?

AC: No not really, no. The sketches were generally then neat enough to show a client. The client would understand they were works in progress. No, we certainly didn't have time to do that. I know that you can start with a sketch and import it into CAD. Use that as a starting point, particularly for surface modelling, but we didn't really do that.

JS: And it did you, I'm sorry, but it just occurred to me, during conceptual design, did you use digital hardware like this Wacon Cintiqu graphics tablet¹⁶⁶ (indicates image of tablet fig 2). Did you use those?

AC: Not the tablet. But you know I had, I think it's called a track ball or a mouse ball. It's essentially a big rubberised ball. It's like a mouse with a sort of shape (indicates an arch shape in the air). I'd use that a lot with the CAD side of it.¹⁶⁷

JS: And then, moving onto detail design, you talked about started to use rapid prototyping? Not necessarily here (indicates development design fig 1).

AC: Perhaps towards the end of it. So, although it's still the development design stage, it's almost infringing on the detail design stage. I mean, we'd only use it on components where we were confident that it's probably a close enough embodiment of what were going to then...¹⁶⁸

JS: And then you would use workshop processes in order to make these physical embodiments?

AC: No, we'd use rapid prototyping. Yes. There were two stages of rapid prototyping for us. We had stage one, which would often be a UK company. And those prototyping models were a bit more precise, a bit more of a finish on them. There was an online organisation, I think they were based in Belgium, where you could upload your file and I think, within 24hrs, they'd send you the rapid prototype. But it was much rougher. It was considerably rougher. But for big shapes, once we were designing a beverage container, um, for things like that it was adequate enough to give you an idea of the shape and form. But for things with a bit more precision we'd use a different company.¹⁶⁹

JS: So, when you were using the rapid prototyping, what was it about the rapid prototype as the embodiment of your design ideas as apposed to 3D modelling that made rapid prototyping useful? Why did you feel it was necessary to be using rapid prototyping?

¹⁶⁵ 07AC_TOOL CAD

¹⁶⁶ The Cintiq is a tablet/screen hybrid, a graphics tablet that incorporates an LCD into the digitizing tablet itself, allowing the user to draw directly on the display surface (Wikipedia).

¹⁶⁷ 07AC_TOOL Digital Sketching

¹⁶⁸ 07AC_Detail/Development design and TOOLS

¹⁶⁹ 07AC_TOOL RP

AC: CAD can take you only so far but you reach a point where you need to prove if the concept works or not. So you need real bits in your hand. Even if it's only in a crude way, you need to show a client that when you twist the button something moves which then engages with something else. You need to show the mechanism for real. And while CAD shows that perfectly, it's not real. It's all virtual. SO you need to show in reality.¹⁷⁰

JS: So you're talking the use of CAD as a communication tool?

AC: Yes.

JS: Predominantly for the client and others to get them to understand what you're doing. What about yourself, when using RP models. How much was it an aid to your own understanding of the direct of your design ideas? What I mean is, were their instances when you rapidly prototypes came into reality...no that's not right. Let me rephrase, how close to you're understanding of the design was the rapidly prototyped embodiment from the computer to the physical. How close was it to what you had imagined?

AC: Good question. Usually pretty good. However, we had several, several occasions where rapid prototyping was completely different to what we had on the screen. The problem there was that the components we were working with were very small. And perhaps one of the biggest fallacilites with CAD is that you can zoom in. And you sometimes get so engrossed with the mechanism that you forget the sense of scale. So you're making changes which are equivalent to a tenth of a millimetre. That sort of dimension is invisible to the human eye really. So you've got one component, and I remember the three of use looked at it and said immediately said that's not going to work. It was this tiny little component about three quarters of an inch big. Um, we just lost that sense of scale. So I think the rapid prototyping, it is a very accurate representation of what you've got on CAD. The problem is sometimes you forget that that CAD at a certain scale. So I think it's more of a problem on the CAD side and your mind than the rapid prototyping, yep.¹⁷¹

JS: Can I just bring you back to one thing you said about rapid prototyping, just before. You described it as being inherently limiting. You were talking about the use of it here (indicates development design, fig 1) could you talk a little more in the limitations of RP during development design?

AC: Yes, when we were developing an idea, often it was a lot of mechanical design so we needed bits to integrate with one another. We needed bits to slide along one another. With rapid prototyping parts, you know, we'd do the usual tricks of using talcum powder to smooth out the surface and we'd sand them. But a lot of the materials were inherently sticky so we couldn't get a lot of the mechanical properties out of it that we needed. So it wouldn't really have been useful to use at certain stages in the development process. Um, we would have had the bits but they just wouldn't be able to do what we needed them to do, just because they were the wrong material. We would completely.¹⁷²

JS: There is one final part to this interview. Let's say that you were to go to a graduate show, perhaps New Designers', if you are familiar with that? Or you go to a university graduate exhibition. Thinking particularly in terms of the graduate's ability to use design tools. So in terms of their ability to represent and communicate design ideas, through the use of various tools, what would you be looking for in the graduate designer's portfolio when considering them...or what do you think it's most useful for a junior designer to have in terms of their ability to use industrial design tools? What kind of skills set would be most useful for them to have?

AC: Personally I'd be looking for working prototypes. Um, I'd want to see that they could create some thing that works, that they have an understanding of the guts of a design, rather than the aesthetics side. While that's very important, um, you know I'd also want to see evidence of CAD, I think that's very important, visualisation tools. But I think predominately, probably, how some thing works. I'd like to see some thing working. And, certainly, intelligence about materials and how they behave.¹⁷³

¹⁷⁰ 07AC_TOOLS RP and CAD

¹⁷¹ 07AC_TOOLS RP and CAD

¹⁷² 07AC_TOOL RP and Development design

¹⁷³ 07AC_Skills Set

JS: How you would get to that intelligence. You were talking about perhaps you'd be taking to them and you'd be going through their thought process?

AC: Yes and also just looking at the, looking through the design if something's working, just to see what selections have been made and why. So yes, like you said, through talking to them I think.¹⁷⁴

JS: OK. Now just one final question. I'd like to go back to sketching, if you don't mind.

AC: Sorry, I'd like to go back because I forgot to mention sketching. I'd be looking for sketching because I think it's really important to be able to sketch and show ideas in sketch form.¹⁷⁵

JS: It's really important and as important as the CAD? Important in another way?

AC: I think they're equally important. They can combine. Personally I don't think you look for somebody who's very good at one and not the other. The right mix of both.¹⁷⁶

JS: Sorry Allesio, Could I also bring us back to the sketch? I mean we talked about using there, the sketching at conceptual design stage. Would you say you don't sketch during development and detail design? You've stopped sketching? Do you move away from sketching?

AC: Because I know I've used sketching during detail design, but it's perhaps more, I hate to say it, but perhaps more trivial detail design. Um, you have things like putting ribs on the outside of a product. If they look better angular or pitted. Um...¹⁷⁷

JS: So problem solving. Are you talking about problem solving?

AC: Yes, so you know what I'd do I'd look at a couple of screen grabs and then just, over the screen grabs, just start sketching in different ribs, different styles of ribs and just seeing which one looks better before actually doing anything in CAD. So yes, it's funny, I still do use sketching at detail design, just in a different way. I was more kind of penning over a CAD image. But I certainly used it.¹⁷⁸

JS: Ok, interesting. Now just one last question, during your design practice how far into the engineering for manufacture did you go (indicating engineering for manufacture fig 1). Some designers have described a process where they hand over, and they might hand over at different stages. Some industrial design firms also talk about having influence all the way through the manufacturing process and beyond. In your experience how deeply into design for engineering did you go? The overseeing of the manufacture of the artefact?

AC: We went as deep as actually instructing manufactures as to how things should be assembled. Um, and we recommended the materials.¹⁷⁹

JS: And in those cases you'd use your 3D CAD representations data to communicate those instructions, intentions?

AC: Yes, we would. But we'd pull off 2D drawings from that.¹⁸⁰

JS: To aid specification?

AC: We'd specify finishes, tolerances and material selection.¹⁸¹

¹⁷⁴ 07AC_Skills Set

¹⁷⁵ 07AC_Skills Set interjection about TOOL Sketching

¹⁷⁶ 07AC_Comparison TOOLS CAD and Sketching

¹⁷⁷ 07AC_TOOL Sketching in Development and Detail design

¹⁷⁸ 07AC_TOOL Sketching in Detail Design

¹⁷⁹ 07AC_Detil design

¹⁸⁰ 07AC_TOOLS in Detail design

¹⁸¹ 07AC_TOOLS in Detail design

JS: And during that specification you talked about using sketching. If a problem was identified is that where you would bring in a sketch in order to communicate a problem area to manufacturer or client?

AC: Perhaps with a client but what we'd often do is we'd take a CAD image, a screen grab, and just Photoshop¹⁸² an arrow where the issue was. We just found that it was much clearer and easier for the manufacturers to understand that than to sketch anything and scan it. We'd just Photoshop a text. Or we'd make the changes in CAD and then Photoshop a sheet and show exactly what we've done.¹⁸³

JS: Was the manufacturer in a different geographic location?

AC: Yes they were. We would have an occasional visit. When things got desperate my line manager would go.

JS: Well thank you very much. As always it has been a pleasure and a great help to my research and understanding of design tools. Thank you.

Interview: ST01

Interview	ST01
Interviewee	xxxxx xxxxx (St1)
Institution	Kingston university London
Course of Study	Bsc Product Design
Year of Study	3 rd Year
Interviewer	James Self (JS)

JS: Ok if I could start by showing you this. This is from published work from design academics and it suggested a model of the product design process [showing a copy of fig 1 to interviewee]. The model they've suggested goes from an open ended conceptual design stage through development and into detail design, that's prior to manufacture. So you've got one two three four five stages, and that they've suggested that these stages are iterative, meaning that the designer will be and flow between them. But generally speaking, there's a progression from an open conceptual design, to a more defined detail design stage of practice. I just wondered if you could give me your reaction to that model, what you think.

St1: Yes, I defiantly agree with that um...

JS: Is that how you work?

St1: Yes, defiantly, so this is where you're coming up with lots of different concepts of vague ideas [indicating concept design, fig1]. And scribbling things down. And just noting everything down that comes out of my head and kind of picking ones that works or talking about them then developing those ones and looking into different ways of doing one. And then, from there, going into models and AutoCAD and things like that, in to the detail. And yes, I agree you do have a jump between them. So if you've got, if you've developed one thing and then someone says but they do not seem to fit. So you're drawing it in AutoCAD and then you suddenly hear this and then, yes of course. Then you go back again and, kind of, look into that. So it's kind of this whole squiggly pattern of thought. So I defiantly agree with that.

JS: So what I'm looking at is the way that designers, when engaged in design practice, will use this whole variety of, as you said, model making, sketching, sketch modelling and ADOBE software, 3D CAD and as to where these tools fit into this process. So the remaining few questions we'll be talking about tools in

¹⁸² Adobe Photoshop, or simply Photoshop, is a graphics editing program developed and published by Adobe Systems. It is used widely by industrial designers to embody and manipulate existing embodiments

¹⁸³ 07AC_Comparison of TOOLS CAD and Sketching

terms of concept, development and detail design [indicating fig 1]. So thinking about this end of design practice, concept design, could you suggest which tools you would most often use to support conceptual...?

St1: Concept design would be just sketching. Sitting and drawing. Sort of working drawings and sketches for myself rather than deep down, nice neat drawings. Often really rough drawn on top of one another, heavily annotated.

JS: So just sketching?

St1: Just sketching at the concept stage, yes. And then, doing kind of sketch models, so, roughly cobbled together out of paper...

JS: Foam models, paper and card models?

St1: Well yes, foam and paper and masking tape. And then sometimes MDF. We've got a big workshop so doing things quickly in MDF as well.

JS: So you're sketching, at this end [indicating concept design, fig 1] and your foam cobbling together the foam models or the card models, what is it about that sketching and cobbling things together, that is useful to you during concept design. Why is it you use sketching as apposed to using 3D software, for example?

St1: Well because, with the sketching it's so easy to just, you can get out so many different ones really quickly. And if you don't like something you can just draw over it. With the sketch models, if I'm using paper or card, I'll just sit and do loads of different ones in sort of an hour. And the same with drawing; do about twenty drawings an hour, ish. Where as, if I was to use 3D modelling, CAD, that would probably take me an hour to do one or two. You know, depending on how technical. Because if it's got really tiny components I can just draw them in really quickly. If I'm sketching them, and I know, it wants to be there and it looks like this [performing sketching motion using hand on the desk]. Where as if I'm doing fiddly component, doing a cog or, I'm working with a winding mechanism at the moment, and if I did that in Solidworks, I couldn't draw that up really quickly and make it look how I want. Do you see what I mean? If I do it by hand I can just draw it in and say that I should get there.

JS: So you use sketching here [indicating concept design] but you also might use it to support your design work here [indicating development design, fig 1] and here [indicating detail design, fig 1] with detail design?

St1: I think this is more thinking [indicating concept design]. Drawing to think and working things out. Yes, to try kind of work out how things work as well. If I take something apart and draw it by hand, and just look at it and just quickly draw, I can work out, or learn how it all fits together and works much quicker and much better than sitting and making models of it or drawing in AutoCAD.

JS: Ok, interesting. So sketching, drawing, thinking: interesting. And then moving onto development design, so you're coming, I suppose the design might be getting tighter. I lot of practitioners have said to me they use, what they do is upload their sketching onto software, sort of ADOBE illustrator and sort of manipulated. Is that something you guys do here? To make it more presentable or to, sort of, they presented to clients after the conceptual design stage. I suppose you have the same thing presenting to tutors.

St1: Yes, sort of, a lot of it, I'm doing portfolio work at the moment. And that is, doing drawings, taking them from my sketch book and kind of scanning them in and having them all on one page in Illustrator or Photoshop. And maybe doing a little bit of, I wouldn't draw on top of them. It's more about composition. So that when I'm presenting I can show all of the ideas on the one page rather than flicking through my sketchbook and going that's quite good. And it would be a big mess of the sketchbook so. And then the presentation boards. Using Photoshop, I use a lot of photos, rather than sketches...I use both but...

JS: Photos of your models?

St1: No, no. Photos that kind of support the context. So if you're designing a teacup, I'd annex four students. I'd have lots of photos of students using, drinking tea or things that have kind of inspired the concept.

JS: Ok, interesting, so sketching then you take some photos and then... Do you guys do you still use hand rendering here, marker rendering as well as the digital?

St1: Yes we do, I mean we're not taught it, we kind of teacher ourselves. Yes people do that on the course. When I'm working I kind of draw it in my sketch book over and over and over again taking every thought of it.

JS: So when you're starting to get here [indicating development design] with your sketching, which I suppose starts off quite broad, and then you're trying to narrow things down, so you'll be sketching and then you'll pick out one design direction and sketch it a few more times?

St1: Yes, yes, sort of variations on that one. Um, and yes, narrow it down and down and down until I've got, sort of, nearly at the one. And then go onto Solidworks and use that for, kind of, drawing the one. And then often, though, when I've finished one drawing on Solidworks I'll look at it and think well, that doesn't look quite right. And then I'll do, sort of, I don't know, maybe five different solidworks ones for that project.

JS: So sketching on to here [indicating concept design, fig 1] and then you go from here onto solid works, so there's kind of a jump between your sketchbook onto Solidworks. When you're working with Solidworks do you have your sketch book here [indicating desk in front] and Solidworks here [indicating place next to]?

St1: Yes, defiantly, work from sketch book. Also, probably because I'm BSc, I annotate all my drawings with measurements and things like that, so I can just take it directly from the sketchbook then and measure it all up and make it look. But, sort of, while this is all going on, from, sort of, halfway through the concept development, well from the start of development I suppose, while I'm halfway through my sketchbook and even up to using Solidworks I suppose, I'm also making MDF models, in the workshop.

JS: As well as work in the sketchbook and Solidworks. Why do you feel the need to make these MDF models?

St1: Yes, because you can get a sense of how it feels, the weight of it, well not necessarily the weight, but the size and, and the feel of it, rather than. If you're looking at it on the screen you don't get how it will fit into your hand or things like that. So that's why I do the MDF models as well.

JS: And you're also working, it sounds like you're working between the Solidworks software and your sketchbook. So you may be sketching something in your sketchbook. And then go back to the model and change it...

St1: Yes, um, generally when I've got to the Solidworks stage, I'm just tweaking on Solidworks. I'm predominantly working in that. And I'll print them all out and, and if I think I want to change a little bit I'll draw over it and put it in my sketchbook and then go do another Solidworks model. From that, do the technical drawings. And then from those, make the final models. So that's kind of that's getting into the detail.

JS: You said you make five different Solidworks models, are they five different models, with five different directions?

St1: No, there're sort of, slightly different variations on the final idea. So I, I'm not sure if I have this. You see how these [indicates printout of different Solidworks models]. You see how these are. There are five different, slightly different designs here. Where this has, this is a lot shorter or flatter (indicating first design) but this is, has this band across it (indicating second model) and this is different again (indicating third model). That height but with that band. And so it comes out in that kind of way.

JS: I see. So you're manipulating the same model but changing, changing the detail?

St1: Yes, changing little details.

JS: And then, do you have a 3D printer or rapid prototyping machine? But you decide not to use that. You do it all by hand?

St1: Yes. I have used it in the past. It depends on the project I'm doing. For this one, it depends on the price as well because we have to pay for it. If I'm doing something quite small. In the second year I did a bottle, I was designing a bottle top and it was made of different plastic and all this thing. And it had to be an economic design. So I made that in, I rapid prototyped that. Because it was so small I could get away with making it quite cheaply.

JS: Was that a rapid prototype made right at the end of the project?

St1: No, I was sort of three quarters of the way through, I'd say. I made it and then, just sort of saw how it went and felt and then changed it a little bit and then made another one. And that got, that second one was the final one. So it's similar to the way this [indicating first Solidworks model] where I've tweaked it a little bit.

JS: Just one more thing now really. Do you guys use there graphics tablets here [indicating Wacom Cintique tablet, fig 2]?

St1: Not in product. I know people in sort of illustrator, TV and film production use them, but, no I don't

JS: Ok, that's all thank you very much for your help, most valuable.

Interview: ST02

Interview	ST02
Interviewee	xxxxx xxxx (St2)
Institution	Kingston university London
Course of Study	Bsc Product Design
Year of Study	3 rd Year
Interviewer	James Self (JS)

JS: Okay, I'll start by showing you a model of the design process [showing fig1]. This is a model some academics have used to describe the product design process; moving from concept, through development and into detail design. These arrows here [indicating arrows between stages, fig2]] indicate iteration. So the industrial designer will move through, go back, and move through again. But it is in these three stages that the designer will use a variety of different tools: sketching, 3D software, model making, in order to support the development of the idea. And I just want your initial reaction to this as a model to the industrial design or product design process.

St2: Yes. I think it's a pretty standard model. Yes, I think IDA kind of do this kind of thing particularly well. Yes, it's a pretty standard kind of thing. It seems to work quite well. There aren't that many problems with it apart from, maybe, the client at some point. You kind of have to go through the client a say, we're working on this, how, what do you think? Is this kind of right? At different stages of the process. Which is standard probably?

JS: Is this how you work? Obviously there are stages where you present to the client or present to the tutors here. And then it moves back. But generally speaking it goes from an open ended to a more constrained end of design practice?

St2: Yes.

Js: Given that then I'm just going to talk to you, in the context of concept, development and detail design. So, thinking about your conceptual design work at the front end, what tool or tools do you use to support your practice, your design work there [indicating concept design, fig 1]?

St2: Sketching is definitely, you know, a big part of concept development. It kind of enables you to get your ideas down quickly and effectively and communicate your ideas well.

JS: is that conventional hand sketching like this guy's doing here [indicating tool in taxonomy, fig 3]?

St2: Yes.

JS: So you don't often use these graphics tablets [indicating digital sketching, fig 3]?

St2: I've never actually used the graphics tablet. I kind of, I'm always quite worried about using computers for things like concept development, because they're quite slow in the way you can get your ideas down quickly. And if you're not 100% comfortable using a piece of software, it will restrict you.

JS: So if you're not happy with the tool its-self, if you haven't spent the hours to learn it?

St2: Yes. But there is, kind of, learning a bit of software and there's *learning* a bit of software, if you like. There are lots of stages of, kind of, how good you are at a bit of software. And to be, kind of, good enough to do what you want to do. They're usually for specialist people doing Solidworks drawings or AutoCAD drawing or whatever, And as designer we are, or I get the impression we expected to be, jack of all trades master of non, if you like. So we are expected to be able to do hand sketches of that quality [indicating image of hand sketch, fig4], and we are expected to produce, you know, CAD drawings of that quality [indicating image of CAD drawing, fig 4].

JS: Do you think it requires a different skills set to use there different tools? Is sketching learned in the same way that 3D CAD is learned?

St2: Well they kind, they don't really run classes on sketching, you're just kind of expected to do it. I mean in a sense of, of academia, I personally don't think they put enough emphasis on the hand sketching and the importance of it. They put more emphases on this kind of stuff [indicating CAD images, fig 4], which is, often, I find, used badly by people because they don't know how to use the tool, to a certain degree that, it affords you to be able to use it at.

JS: Could you expand on badly for me?

St2: It doesn't communicate very well. If you're presenting a concept to a tutor, and your concept's done on Solidworks, Solidworks or CAD, 3D CAD in general, has this affiliation of the product is finished. Because the detail is great and the level of accuracy is so great. And so you can see a concept on Solidworks or CAD and be like, you know, that's kind of scary. I don't really like, I don't like this bit, I like that bit, and I don't like that. But, because of the details are so great, you have this affiliation that it's finished. So to present a concept in CAD is not a good idea. Where as sketching you have a freedom to it, it's like, you know.

JS: And do you think that might, as well communicating in a way you don't want it to communicate to tutors or clients, do you think that could also constrain the designer using CAD? If they are using CAD in that way, they may be constrained, rather than sketching allows you to sort of float around different ideas?

St2: Yes, defiantly.

JS: Do you also use sketch models as well during conceptual design? Foam models or card models?

St2: Yes, yes defiantly. When I do it I try and make the material as realistic as possible. So, if I'm making something out of wood, I'll try and find the exact wood I would use, to get the right idea of how it works

its proportions. But I understand in things like this plane [fig 5] it's not always possible to do that. So in order to try and get a feel for proportions and things like that, it's really important to do it.

JS: Do you use sketch models once you've got, sort of, four, five or six design directions from your sketchbook? So sketchbook is first. Then you'll sketch around and then come to some design directing and you'll want to feel it in your hands. And then go off and sketch model it?

St2: Yes

JS: And then you might go back to the sketchbook and go and refine those a little bit more?

St2: Yes, and then go and do that [sketch modelling]. But it is also kind of important, depending on the way you work as a designer, to have more idea of details when making a model. It's not a case of, you know, right okay I've got this sketch and I've got a block of foam. You know, go down to the workshop, I'm going down to the workshop. I'm going to make this. Because you've got no idea about dimensions or anything like that. So it is good to kind of put some basic dimensions on your sketches I think. But, it's kind of half-way between sketching and that [indicating?]. So it is kind of important. But some people can just get a block of foam and get a sketch and go into the workshop and just make something. It kind of depends on who you are and what your skill set is.

JS: So then you've done, you've done your sketching and you're going into development design. Designers have described different ways of communicating. What they may do is they communicate with the client. They have a client meeting after concept design. And, so to take design directions forward, sometimes they'll use hand rendering, often they'll work up some of these sketches using ADOBE Illustrator, something like that. And present that to the client. Others don't. Others present their sketch book to the clients. I wonder what you do with your tutors. Do you render, do you sort of, bring some sketches together and present them on a board or something like that?

St2: Yes I do. I mean I much prefer to refine the sketches from thinking sketches, as I tend to call them, to doodles in a sketch book to taking them out, tracing them. Making them look better, communicate better. Purely because of the drawings, but obviously these take quite a while. But again it has that softness that CAD kind of doesn't. CAD is kind of very harsh and, you know, finished. Whereas the sketching is like, well I don't really like that, you know. Can you do, you know, can you change this? Can you change that? And then, if you've got your sketchbook there, you can do a sketch right in front of the client and say, do you mean like this? And again you'll go yes I know. Where as if you've got a Solidworks model, I mean you're, well hang on I'll be back in an hour, you know, I'll go and change the err, change that. Then they'll probably go no I don't like it anyway. But yes sketching kind of very easy to change and very easy to work with.

JS: So, do you use 3D software? Ok, so where does that come in?

St2: Yes.

JS: Where does that come into your practice?

St2: I don't really like it. Not because I can't use it, because I can. But I don't really see the point in using it until you're finished. I mean really finished. Unless, of course, you're trying to produce drawings from it to work a model and then it's pretty good. But I'd never produce something like that [fig 5] in that stage [indicating development design] because I don't really see the point of it. It's very kind of harsh.

JS: So you work with your sketches?

St2: Work with my sketches...

JS: Define your sketches. Then, once you've got a really good idea of your design direction then you might use a well that well defined representation in your sketch book to produce that [indicating 2D CAD image, fig]?

St2: Yes.

JS: To get your dimensions. So that is literally, that is for your, sort of dimensions?

St2: Yes. They are a working kind of drawing to produce a more refined version of that [indicating 3D CAD image, fig]. I'd rather go to a meeting with a load of pretty sketches and a model than something like that [indicating image of 3D CAD, fig]. Because I think you can produce something like that [fig?] in a model and it will communicate much better. Clients can pick it up. They can feel it. They can go, well, I don't like. When they see, this kind of thing with loads of reflections on. They can go oh my god I don't like, this is finished, no I don't like it. Get me out of here!

JS: That is often coming out of practitioners the problem with CAD.

St2: I didn't learn that at university, I learnt that from work experience and stuff, because they kind of said they lost clients on the back of producing CAD models. It was for a yacht interior company. And the client kind of saw his master bedroom on his yacht you know, oh my god, you know I don't want three draws in my bedside cabinet, I only want two. Whereas sketching kind of allows you to be more flexible.

JS: Would you say it communicates the fact that this is a work in progress?

St2: Yes.

JS: Ok, then, would you use rapid prototyping. Of course in order to use rapid prototyping you'd need a 3D model. Do you use, or would you prefer not to use the rapid prototype and you'd hand make your?

St2: I would hand make it, if I could. I don't see anything wrong with using the rapid prototyper to make parts that, kind of, don't afford wood or foam very well the small details. It's obviously a lot quicker to rapid prototype rather than try and make it, break, it, you know, finish it. So I use it in conjunction with model making. But I doubt that I would ever, kind of, make a model, get the whole thing rapid prototyped because I'm not that kind of way of working. I prefer to work with my hands, it's, I think, there's a lot of satisfaction...

JS: And there's something about working your shape with your hands? Would you say it's useful to be able to create something in your hands, to be able to manipulate it?

St2: Yes, defiantly. It allows you that affordability. This is too big. I don't really like that. But you can then change it as you're going along. If there are any problems with it, you can change the dimensions. Where as, if you rapid prototype it. You rapid prototype it, think that's too big. I don't like that. Change it on Solidworks, through your rapid prototype model in the bin. Do it and gain. Do it again. Do it again. Do it again. Do it again. You end up with these millions of models. Again, it's a bit like CAD. They've got no feeling to them. They've got no, I just think they're just very harsh. Unless they're finished exceptionally well and then they can be quite good but...

JS: When you say feeling, harshness. This 3D modelling, digital rapid prototyping, digital technology. You think it's all got a certain feel to them? The communication of ideas through this technology has a certain feel to it? It's distinct to digital technologies?

St2: Yes. Yes. Yes. But, again, it allows people to do, that aren't great with there, hands to do...to do that. But I don't really like it. I would never produce something like that (indicating image of 3D model again, fig)

JS: Thank you for your time.

Student Interview: ST03

Practitioner Interview	ST03
Interviewee	xxx xxxxx (St3)
Institution	Kingston university London
Course of Study	Bsc Product Design
Year of Study	3 rd Year
Interviewer	James Self (JS)

JS: I'll start by showing you this. And that is a model of the design process. It consists of five stages but these are the ones I'm most interested in most, concept design, development design and detail design. These arrows (indicating arrows on model of practice, fig 1) indicate iterations between stages. So work may ebb and flow as the design progresses. However the model suggest a general open ended concept design stage that gradually narrows through to a constrained detail design stage and then off and on to manufacture. I just want to get your initial reaction to that model. Do you agree or do you think there is something missing?

St3: I think the actual model is I mean there is the model. That sort of perfect model. But there is no actual physical perfect model that can be set like that because every design is different. And sort of the design and the flow is sort of takes its own model, there is no way. You can always base. Have these bases along the way (indicating concept, development and detail design, fig 1) but it's probably difficult because the research might take longer, you might come across some research and want to explore more. So, have these set constraints is very, very, difficult. You can have these times when you want to, I want my concept by here (indicating concept design, fig 1), I want my develop by here (development design, fig 1); want to have detail by here (detail design, fig1). But, as you say, each one can affect the other ones. And the fact that if you get to development and find out, that's not a good idea, you can always jump back and it could affect the detail. Or you could get the details and find that the detail makes the concept better. So you could get right to the end and realise at the star you've got something completely different and. The essential rout is correct. The essential way that you work is like that. But it's not as constrained as that. I don't think you could put it down to those three parts because it's sort of all merge into each other. The development comes with the concept design. And the sort of detail comes with the concept as well. So you sort of. I would say it all sort of stems from the concept. Because you, when you're developing concepts you get details on different types of concepts. And the way I work, I don't know if anyone else works, I'll take, sort of, all different parts of the concepts and bring them together and develop the concepts fully. Sort of exploring into all of the details. So sometimes detail comes before development, in a way that, um, development comes from the detail.

JS: Good. Interesting. Ok so thinking about, you talked about your concepts, what, When you start off. Obviously you're exactly right. It does depend on many things including the brief and the research, the, what you'll do and when. But generally speaking, what tools do you use in the beginning to get your ideas out?

St3: What you mean onto paper?

JS: Yes.

St3: I'm not the greatest drawer. So sort of sketching, I try to keep that to a limit. I'm a very sort of thinking person. Because I've got all these ideas going round in my head. And I sort of, almost sketch ideas in my head before I put them down on paper. All the concepts and ideas I think of, they go down onto paper. And I sort of put the key ones and just have them, sort of, not great sketches, more idents just to keep me, so I know what I'm thinking about, they're not great Picassos or anything. But they're sort of idents but I know what they mean. And, sort of, small notes next to them, so I can work with them. And I try and attempt to try and get on to a computer, like 3D modelling software as soon as possible. Just to get the... Because I find if I'm working in 3D, I'm modelling and thinking about, it just helps me get a better view of concept and what something looks like and the way it's going to work. Because it's almost like

using paper first. Because I'm not the greatest drawer in the world and I try and keep drawings as limited as possible. Although working on the screen a do sort of do some...

JS: So you do most of your thinking once you're on the 3D, do you use Solidworks?

St3: Yes, Solidworks

JS: On the Solidworks, so you've done some already?

St3: I mean in concept design I tend to use, sort of, very simple software design, something like Google sketchup, just to get a basic shape on the things and looks and things. And then when I've, sort of explored them, I'm going to move onto Solidworks to get more detail and definite things.

JS: Do you use the Wacom Cintiqu graphics tablets?

St3: I have used them but I only use them for rendering and things like that. Rather than designing things. Rendering models and Photoshop and things like that. I don't use them for design stage work.

JS: Do you use, do you make sketch models, out of foam or paper?

St3: I do. Actually that usually comes at the development stage. I sort of make them, just to see. Like I know I've got some definite ideas and I make them to sort of decide what is better. It gives things people to hold using, sort of use them as for the target market, [inaudible] end models. Because obviously I know what it looks like so, in my head. I don't think you need to have, like, something built. It's more to check its working, thinks like that.

JS: So how do you come to those design directions? Those definite ideas? Is that through 3D tools?

St3: A lot of thinking's involved. It's what I do and things. I've done a lot of time exploring all the possibilities of an idea. I get an idea, try and break it down and, good things and bad things about it, pros and cons. And try and think of all the possibilities that a product, as a product cycle can go through and if that meets the needs of the product. I also look at other products. Existing products and see, does it do it better than this product? If it doesn't do anything better than that product, what's the point in putting it out there. So when, if it meets those, sort of, briefs, then I know it's worth taking it to the pre-design stage and, sort of, exploring it more that way. Cause then its more, if it meets all the brief like that, it's more about the, sort of, looks. The aesthetics of it.

JS: So you get all of that information together. And then you're sitting on it. And then you'll draw on it and start adding.

St3: Once I've worked out it's sort of there with the solution, not sort of the best solution yet, but it's a working solution, then I can start cadding. I can start working out what it's going to look like. How this speakers going to work. Where this handles going to go, where this switch is going to go. Things like that.

JS: Do you use CAD to resolve all those issues?

St3: Most of them. I do have a basic idea through my sketching. I mean I do take the very basic sketches to CAD. But the actual main design of the end solution comes from CAD. My ability with CAD is sort of. I like to do everything through CAD.

JS: When I talk to practitioners they often talk about a client meeting somewhere around here (indicating boarder between concept and development design, fig 2). They say a lot of what you've said actually. About the design process not being as constrained as this. This is taken from old ways of thinking about the process, where this staged approach has been used. But what they've talked about is at a stage here, between concept and development design, where they'll take their ides and present them to clients. Is that the sort of thing you have to do here? As you present to the tutors?

St3: We present to the tutors. It's more, sort of, quite a few times in a stage. Like for the concept designs it will be three or four times. Where, I usually present just more ideas. So the basic idea sketches, and if I can and I've got time, to mock up a sketch up or something, so mock-ups.

JS: You mean a model, 3D sketch model?

St3: A 3D sketch-up. Or maybe, if I've got time to do it, I can knock-up something out of the workshop. Just basic up. Just have some visual to show. Cause I've got it in there [pointing to head] but to get it across to somebody else is a completely different thing.

JS: And then you move into here [indicating development design]. And the result of you working in here is what? Do you take that and then another presentation? Or is that final.

St3: When I've got the final Solidworks model, I then tend to get hold of, to look at. And if I can, I'll get it rapid prototyped. Over here or up at Rhoehampton Vale [another site at the university] just to have a physical, exact model of what it looks like. And from that I can see immediately see this is too long this is too short. Because with, I know it's a 3D model on the screen, it's quite difficult to judge size and things like that. So I do something you can hold, it's easy to say that, that could be a few millimetres shorter. That's the example of the good thing of having a computer. Because again I can just go on there, type a few numbers in and that will shorten that 20mm.

JS: Ok, you do iterate once you get the rapid prototype done, you have a look at it and, oh, this needs a little here, this a little there. And then, if you can afford to, you rapid prototype it again.

St3: Usual, I've only ever done it once. You can usually tell from just that one model. You can just judge that that needs a bit more filleting, that needs a bit more curving. That could be flat, things like that.

JS: So you need a rapid prototype you think?

St3: I mean, it's not necessary, I find it easier. Because I mean, before I have it rapid prototypes I've printed out the drawings and just made a model from the drawings. I find the rapid prototyping the quickest way of doing it. And, I mean, you can do it that way, you can do a sketch model. But the quickest and most accurate, I think is the rapid prototyping.

JS: But you feel you need a physical representation to show your clients, or in this case, your tutors. You need that physical representation.

St3: If I can, I will. If not, I can actually just have a 3D model at my presentations. But in an ideal world I'd show a 3D representation [model/tp] because it's just easier to visualise. It can give us a better view of

JS: When you're working with the 3D software, how much. You have this idea of a design direction, you go on to the software and then, I suppose, you go through some iterations with the software. Maybe you rapid prototype, and then come back to it. How much does your design change from when you get on it with your initial idea to the final outcome?

St3: From initial idea it will change quite a lot. But from that prototype to final form it won't change much at all. It's literally just fillets, small adjustments. But from the first, sort of, from the first, sort of, model to the final model, they'll be major change and things like that, and that will come from research and exploration of development products.

JS: And your interaction with the 3D software. Your doing and thinking. Doing and thinking?

St3: I try to avoid, as much as possible, the limitations of the software. Because I mean if you design to the limitations of the software, it's limiting design a hell of a lot. I try and avoid that and try and if something can't be done, I try to work a way round it. Because I don't like the idea that you're designing because you can't do that on Solidworks. I don't want the fact that I didn't put that in there because I couldn't draw it on Solidworks. That you can only do sort [inaudible] for effect design. That's why I like to go on Solidworks with an idea of what it looks like. Because if you go in thinking you're going to

design it on Solidworks it just won't work. Because you're just going to have lots of extrusions and holes and things like that. It just doesn't work as a concept design.

JS: How far, you BSc students, how far do you go into detail for engineering, for manufacture? Often, from what product designers have been telling me, the product and industrial designers will go quite far into engineering. And they'll specify the construction drawings for manufacture. Is that what they ask you to do here?

St3: We haven't got much past development design at all. I mean we'll often ask us to give like technical drawings but we don't get much further than that. We don't get too deep into that bit. It's probably something, depending on the job, something that's likely to get an engineer's job. But, as I say, here, the most we probably get is engineering drawings.

JS: And they're taken from the 3D digital models?

St3: Yes.

JS: Very interesting. Thank you very much for your time.

Appendix H
IDsite Pilot Survey: Online Questionnaire

What Do You Think?

www.industrialdesignresearch.com



Kingston University London
Design Research Centre

'Design Aid' Website

What do you think of our site? **The questionnaire should take no more than 3 minutes.**

All information will be maintained in a strictly confidential manner in keeping with Kingston University's ethics guidance and procedures. You will not be asked to provide your personal details.

Thank you for your generous assistance and time.

Design Research Centre, Kingston University London.

j.self@kingston.ac.uk

Next

This survey is powered by www.surveymethods.com

What Do You Think?

www.industrialdesignresearch.com



Kingston University London
Design Research Centre

Page 1 Questions about You

Page 1 of 2

1. How would you describe the company/consultancy/organisation for which you work/Study?

Please Select

2. What is your employment/educational position in your organisation?

Please Select

3. How would you describe the design discipline in which you work? Please check all that apply:

- Industrial design
- Product design
- Automotive/Transport design
- Packaging design
- Engineering design
- Interaction design
- Interior design
- Other

4. For how long have you worked in the above profession?

Please Select

[Next](#)

This survey is powered by www.surveymethods.com

What Do You Think?

www.industrialdesignresearch.com

Kingston University London
Design Research Centre

Page 2 Questions About the 'Deisgn Aid' Website

Page 2 of 2

5. How do you feel about your ability to navigate the site? Is it intuitive, clear and easy to use?

Excellent
 Very Good
 Average
 Below Average
 Poor

6. How would you rate the clarity and understandability of textual and pictorial content? Is it clear and understandable?

Excellent
 Very Good
 Average
 Below Average
 Poor

7. How would you rate the site's description of design practice (convergent through concept, development and detail design, but with periods of divergence and iteration)?

Excellent
 Very Good
 Average
 Below Average
 Poor

8. How would you rate the ability of the site to foster enhanced understand of various design tools and their support of studio practice?

Excellent
 Very Good
 Average
 Below Average
 Poor

9. Do you think using the site would benefit any of the following groups?
Please rank all the items using the values 1 to 4. Rank all items below. Use each value only once.

Undergraduate design students	
Less experienced design practitioners	
More experienced design practitioners	
Design educators	

10. How do you feel about the ability of the site to enhance your own understanding of and engagement with design tools during your studio practice?

Excellent
 Very Good
 Average
 Below Average
 Poor

11. Finally, we would be most interested to hear your thoughts, good, bad and indifferent.

4000

12. Would like to be sent a summary of the results? If so, please enter your email address below.

Previous
Submit

This survey is powered by www.surveymethods.com

Appendix I

IDsite Validation: Letter of Invitation

Dear Designers,

Many thanks to all those practitioners who have completing our online survey. Your comments and feedback will influence IDsite's development. To those who have not already done so, could I respectfully ask you for just 5 minutes of your time to view IDsite and complete the short survey?

IDsite: <http://www.industrialdesignresearch.com>

Survey: <http://www.surveymethods.com/EndUser.aspx?EBCFA3B9EFABBBBBBEE> (or click 'Your Opinion?' top navigation bar)

Many thanks for your time and support.

James Self

Doctoral Researcher

Design research Centre,

Kingston University London

email: j.self@kingston.ac.uk


Tel: +44 (0)20 8547 9771

Mob: 077241 91667

www.industrialdesignresearch.com

Appendix J
IDsite Validation: Online Survey


The easiest way to Ask, Analyze, and Improve. - Windows Internet Explorer
methods.com/Preview.aspx?7819F8B8605CFD5C4C197878DC296D98CDD49684C2CFD5C4C0888D868DC3D1D186C1D3C4C2BB80DF83D4A0ADEF8CAB86ECB1ABB2E9ADB0AAFAA1BBAEF9BCAF&DO_NOT_COPY_TH

Tell us What You Think. www.industrialdesignresearch.com  Kingston University London
Design Research Centre

IDsite
What do you think of IDsite?
This questionnaire will take no more than 3 minutes.
All information will be maintained in a strictly confidential manner in keeping with Kingston University's ethics guidance and procedures. You will not be asked to provide your personal details.
Thank you for your generous assistance and time.
Design Research Centre, Kingston University London.
i.self@kingston.ac.uk

Next

This survey is powered by www.surveymethods.com

Tell us What You Think. www.industrialdesignresearch.com  Kingston University London
Design Research Centre

Page 1 Questions about You Page 1 of 2

1. How would you describe the consultancy/organisation for which you work/study?

2. What is your employment/position in your organisation?


3. How would you describe the design discipline in which you work? Please check all that apply:
 Industrial/Product Design
 Automotive/Transport Design
 Engineering Design
 Interaction Design
 Other

4. For how long have you worked in the above profession?

Next

Internet

the easiest way to Ask, Analyze, and Improve. - Windows Internet Explorer
thods.com/Preview.aspx?F5EBFFF2A1BBA1B0B5E3F3F9B6E2ADF8A8AE2F0B68BA1B0B4FFF9F2F9B7A5A5F2B5A7B0B6CFF4ABF7ADD4D99BC8DFC298C5DFC69DD9C4DE8ED5CFDA8DC8DB8&DO_NOT_COPY

Tell us What You Think. www.industrialdesignresearch.com  Kingston University London
Design Research Centre

Page 2 Question 1 of 7 **Page 2 of 2**

5. Looking at IDsite's homepage, how accurate is the model of the design process?

- Very Accurate
- Somewhat Accurate
- Not Sure
- Not Very Accurate
- Not Accurate at All

6. Do you find the images and text effective in helping to describe design tools and their relationship to the design process?

- Very Effective
- Somewhat Effective
- Not Sure
- Not very Effective
- Not Effective at All

7. Would the site help any of the following groups better understanding the role design tools play in support of the design process?

- Undergraduate Students
- Postgraduate Students
- Novice Designers
- Mid-weight Designers
- Experienced Designers

Internet

sn005.com/preview.aspx?fbclid=IwAR1B6A1BDBE3F3F50E24UF046AULZ7UBD6A1BDB9FFF9F2F96/ASAFZD5A/BDBLFT9ABF/AULM959DUBFL290L3UFL69AUSL4UE8L5LFLM90LUBD6SU_IKU1_LUPT_I

Experienced Designers
 Design Educators
 Design Researchers

8. Would IDSite help you to better understanding relationships between the design tools you use and their support of the various requirement of the design process?

Definitely Will
 May Do
 Not Sure
 Will not
 Definitely will not

9. Finally, please use this space to provide any further observations or suggestions to help us improve IDSite.

4000

10. Would like to be sent a summary of the results? If so, please enter your email address below.

[Previous](#) [Submit](#)

This survey is powered by www.surveymethods.com

Appendix K

IDsite Validation: Student focus Group Questionnaire

1. Looking at IDsite's homepage, how accurate is the model of the design process?

Very Accurate:	<input type="checkbox"/>
Somewhat Accurate:	<input type="checkbox"/>
Note Sure:	<input type="checkbox"/>
Not Very Accurate:	<input type="checkbox"/>
Not Accurate at All:	<input type="checkbox"/>

2. Do you find the images and text effective in helping to describe design tools and their relationship to the design process?

Very Effective:	<input type="checkbox"/>
Somewhat Effective:	<input type="checkbox"/>
Note Sure:	<input type="checkbox"/>
Not very Effective:	<input type="checkbox"/>
Not Effective at All:	<input type="checkbox"/>

3. Would the site help any of the following groups better understanding the role design tools play in support of the design process?

Undergraduate Students:	<input type="checkbox"/>
Postgraduate Students:	<input type="checkbox"/>
Novice Designers:	<input type="checkbox"/>
Mid-weight Designers:	<input type="checkbox"/>
Experienced Designers:	<input type="checkbox"/>
Design Educators:	<input type="checkbox"/>
Design Researchers:	<input type="checkbox"/>

4. Would IDsite help you to better understanding relationships between the design tools you use and their support of the various requirement of the design process?

Definitely Will:	<input type="checkbox"/>
May Do:	<input type="checkbox"/>

Not Sure:

Will not:

Definitely will not:

Finally, please use this space to provide any further observations or suggestions to help us improve IDsite.

<hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/>



--

Appendix L
IDsite Validation: Survey Methods Results Database

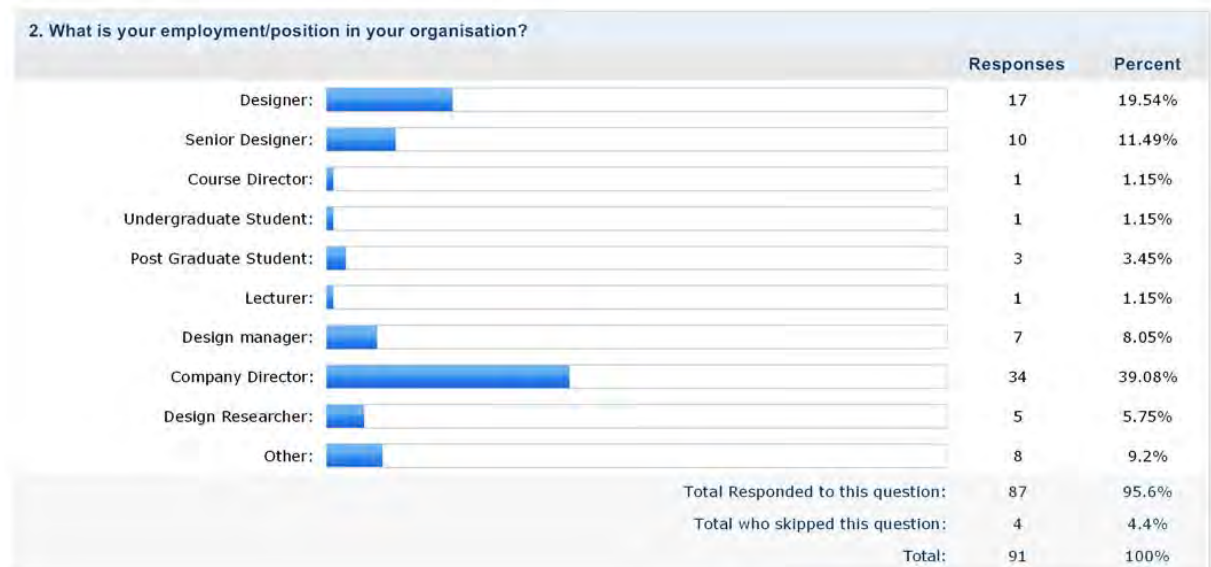
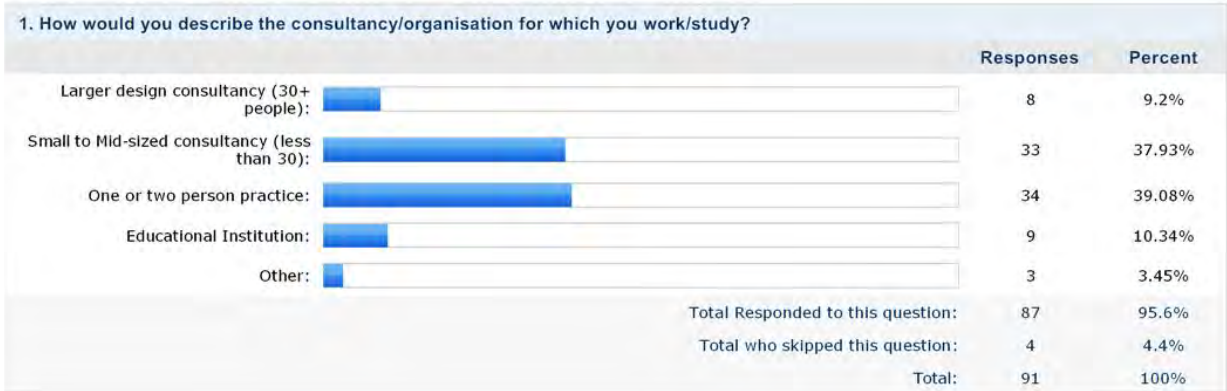


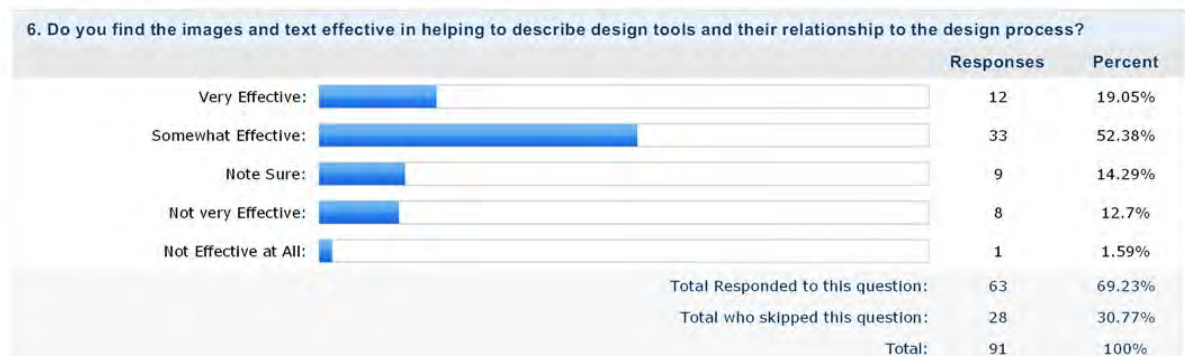
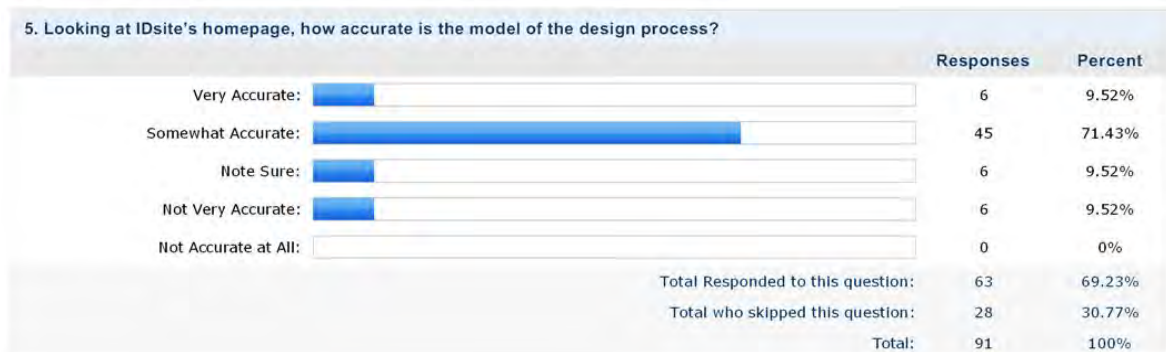
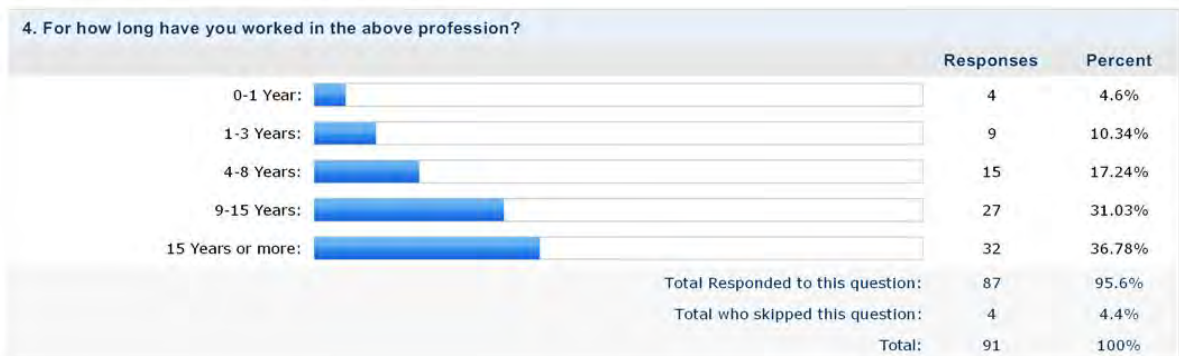
Survey Software: Ask, Analyze, Improve
Survey Creation, Deployment, & Analysis Tools for Businesses

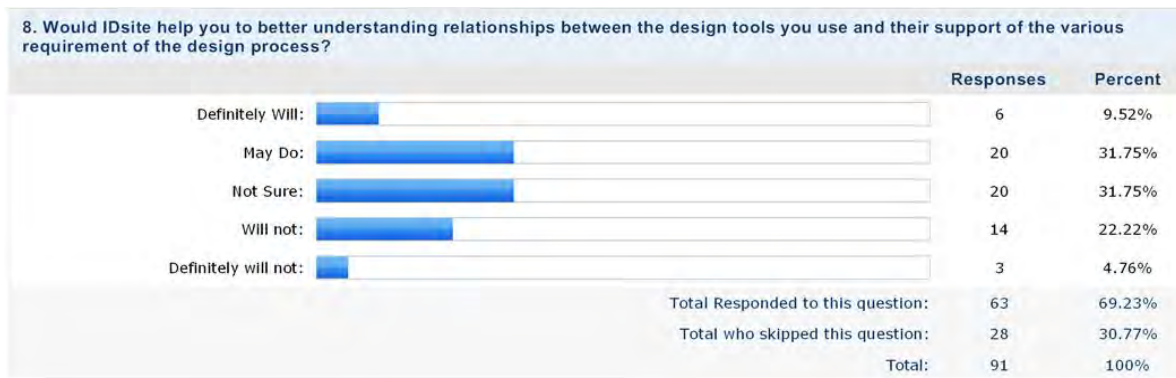
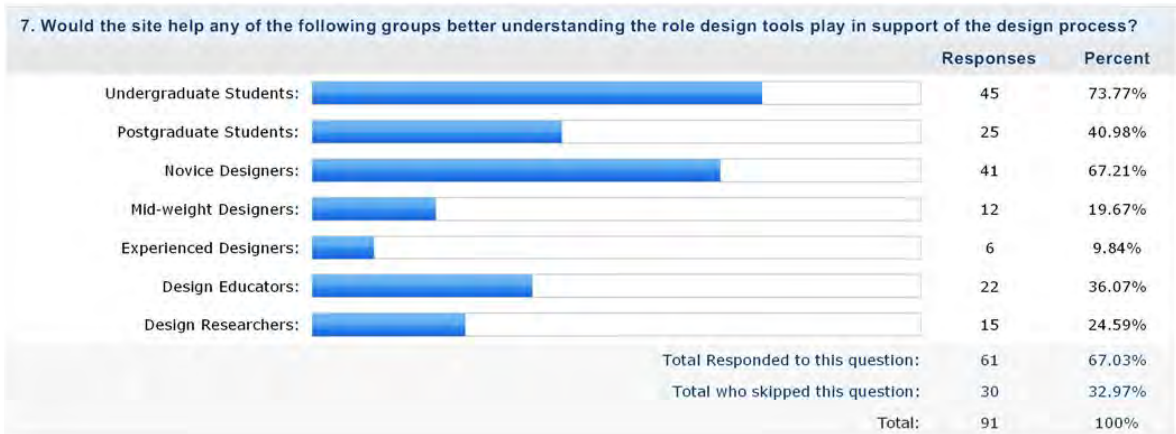
Survey: Tell us What You Think.

Report: Default Report

Survey Status		Respondent Statistics		Points Summary
Status:	Closed	Total Responses:	91	No Points Questions used in this survey.
Deploy Date:	03/09/2011	Completes:	64	
Closed Date:	04/11/2011	Partials:	27	







Appendix M
IDsite Validation: Responses to Open-ended Question

Survey of IDsite validation: Results for Question 9, feedback.

Finally, please use this space to provide any further observations or suggestions to help us improve IDsite?

Respondent 2: Completely redesign the site and stop using Flash

Respondent 4: Site loads very slowly. The information presented is very generic. To be a resource to designers you'd need to have something that contains much deeper information.

Respondent 5: Honestly I was busy and did not spend a lot of time looking at it. I'd like to see it all and be able to download it to discuss with others - definitions images and diagram together on screen. I'd like to keep in contact with your research as it overlaps with work I'm doing and about cross cultural illustration.

Respondent 7: The model appears to be more suited to designers, and not individuals and disciplines that do not understand the design process. Our clients require a great deal of input on understanding applied research, how to interrogate a product's key technologies, and an overview management of budgets and risks. Although the output from our designers is included on your model, we also provide spreadsheets documenting quantitative factors, qualitative style actor-network-theory breakdowns, and importantly copious instances of face-to-face mediations with the client and other stakeholders. All of these tasks can be included in your design-thinking model, and may help to illustrate that the industrial design discipline is not only about the object but also about the social ramifications around the user, client and studio. Hope this helps...

Respondent 11: Several points: • I think that there is a little too much "overlap" of the suggested use of some tools (eg. 3D printer), which could create confusion to someone who is trying to learn the basics, and when to use these tools. For instance, I would only mention the use of a 3D printer in the prototyping phase of a project. • There is too much reliance on some of the advanced technologies, and as good as the programs currently are, (and I have advanced expertise with several major systems), I still find that they can't do everything that I would like to see, therefore it is easy to "compromise" design intent with the convenience of 3D CAD technology and its limitations. • I think that the site is a useful tool to explain the basic design process to students of design, and I like to give my clients a bit of an education of the steps leading from ideation to manufacture, as I prefer to quote my jobs one design phase at a time. This will be a useful tool to explain the process to my clients, if some of the overlapping confusion is cleared up. • I think that this site can be a helpful education tool, and that an experienced designer should already have knowledge of the material presented, however, as I said, I think this could be useful to help me educate a client on the design process, so that I could structure my quotes per design phase.

Respondent 14: it would be nice if you insert into that process: mock ups (large scale models), and user centered design methods and practices as part of the overall design process and intrinsic to it.

Respondent 15: Question 7 should include potential clients and the public. We as designers understand the process but it is increasingly difficult to get your client to see the true value of what we do. They question the costs of each stage yet happy to pay more for their car to be repaired. We should be on par with lawyers and doctors and not car mechanics. They do do a good job though.

Respondent 18: Change the design and the user experience

Respondent 19: It's great what you have created especially from my Designers view. I wonder if clients can/will value such a tool or visual guide of the process, my experience of clients is they don't care much about design process, but just want results instantly and under budget. It would be great to get clients, blue chips, and companies to really understand design process and therefore value it's worth 100%. Keep up the good work.

Respondent 21: I think some of the assumptions made (e.g. level of commitment) could be quite subjective and open to argument. Otherwise quite an interesting site.

Respondent 23: It still takes a long time to load - at least provide a egg timer! (windows 7 + firefox) I think it is a great introduction for students. However I do not see any advatange for a practicing designer as life (and a project/ company) does not follow theory.

Respondent 25: Slow site that I presume was not working correctly when i looked at it. The drop down menus didn't link to anything as far as I could tell. not sure what the point was.

Respondent 30: Design Processes is not always linear... Initial process maybe, but most of the time one needs to pick the tools and mix and match to tailor the process to suite the constraints of a project. I will suggest looking at some form of flexibility and allowing the designer to explore and play around with the tools at their disposal.

Respondent 37: Greater reference to the tooling / manufacturing phase is required. Graduates typically join our company with too little knowledge of machining, tooling and production process. We have to give them more training in this area before they are useful to our company. There is no "design" until the product is at Job 1.

Respondent 38: Perhaps I missed it but IP is a very important aspect of design (incl: Patents, Reg Design, Trade Marks etc) & the Client can benefit greatly if the product design has elements that can be/are protected. Obviously, you have to be properly structured (NDA's) when co-working with other firms that are contributing to the design solution & IP (to avoid public disclosure etc). Perhaps there should be a section that covers IP (& where it fits in with the product design & market assessment/ROI process)

Respondent 39: The model is aesthetically ugly and could use colour better to determine sections and stages. Why is it built in flash? The UI need developing as I didn't realise there were rollovers until I accidentally triggered one.

Respondent 40: It would be useful to relate the diagram to actual tasks, otherwise it looks a bit too theoretical

Respondent 42: screen loads too slow need to optimise images or load in background

Respondent 43: Doesn't work in Chrome, content is not always as expected, e.g. why is the description for design activity different if accessed from text on LHS and graphic RHS? You shouldn't need to tell user to click ... click In the end I'm not sure what it's for exactly, it's a nice enough explanation but it feels very passive and text-bookish, and like many process diagrams, not particularly interesting or inspiring.

Respondent 45: Add links in order to expand on actual processes being used so people can dig a little deeper.

Respondent 47: i see diagrams such as this to be effective in teaching design. We are in a process driven industry and this is reasonably correct. as a tool to comunicate in industry practice it is too complicated. clients want to understand a basic level of our process but diagrams like this can be studied for a while, for the untrained eye it is a little complicated.

Respondent 51: You should have REAL graphic designers improve the information design. It looks like ID students designed it. The information is solid.

Respondent 54: the site is not very intuitive and information is hard to read with the interactions on navigation confusing content....

Respondent 55: Not clear as to what the site is trying to do. Flash pages take some time to load then race through the presentation. I have no clear understanding of what it is trying to say.

Respondent 59: I'm on a 13" Mac and first completely missed the tools menu on top since I had scrolled a little to see the content area better...

Respondent 61: Improve graphics and for heaven's sake get rid of all those animations!!

Respondent 62: The content seems to be OK but not very engaging, intuitive or helpful for people beyond the design profession. Please use a professional information and interaction designer to improve the site. The process diagram is convoluted, the drop shadows are unnecessary and even distracting. The space for real, meaningful content is too small. Core methodological practices such as user research, human factors, opportunity mapping,

prototyping, usability testing are missing. It seems like a dated concept model. Feel free to contact us at Experientia.com for help or our process descriptions, check out also the process tools from the British Design Council. Good luck, Jan-Christoph Zoels

Respondent 63: This is the process my business works around. <http://www.iterign.com/process.html> This is partially based on lean/agile techniques but also incorporates the plan do study and act process of improving things developed by demming for manufacturing process improvement in structured way. And using TRIZ to solve contradictions rather than relying on inspired thought. I see that people from outside the industry don't understand concept design, detail design and all the different terminology. The process as we drawn up ignores these separations as they are a distraction and can be stripped back to a much simpler purer process which will work in most applications from new design. I think that the industry needs to start adopting simpler systems not expanded drawn out methods that just confuse. As not all projects start with a concept and sometimes even quite late in the process it may necessary to return to the start. We identified that in the industrial/product design industry there is too much scope for inspired thought and not enough focus on improve the quality of the system and working in a controlled way. Our website does need images as things at the moment are at a very early stage business was only started trading in April! I penned the term iterign as a taking iterating cycles and reviews as an a very important part of the design process that when ignored and brushed over lead to manufactured products that just don't perform. A key thing also is that most things made are just a compromise of different problems and never the optimum ideal solution if you kept on trying to achieve perfection you would never release anything into production. The key thing is if it meets its functional requirements, and if these requirements are well researched then the product should perform well. I would be interested in the result of your survey, and feedback on our process aswell. The site does not work in google chrome, the drop down menu failed to display. I do have a very slow internet connection (line fault 120Kb) so that may be the reason for this. Best Regards Alan Lawrence

Respondent 64: All the information is correct and appropriate, however, the "look and feel"/graphic design elements/colours/immature flash movements are just not that sexy. To reinforce/demonstrate the design process the visuals need to be dynamic and well thought through. This website design is a very generic rendition of the product design world and how individuals view and think that world should be...it's just not that interesting! It looks like a student project

Respondent 67: I wasn't really sure what this is meant to be for.

Respondent 68: Make it work in google chrome. A lot of menus do nothing. I'm not going back to firefox to use 1 or two sites that don't work in chrome.

Respondent 74: Hi, This website is quite accurate but I would like to see much more about "management by design" and not only about "management of design". I mean much more about marketing by design, around target and users (SWOT Anyllis, etc ..) which is more what we expect of graduated designers.

Respondent 76: Dear James, I'm not sure what you aim to achieve with this activity. The site you have created is not new and only informs on a very basic level. I wish you every success and want to offer some brief advice. How do you aim to support designers? What is your goal? I understand that you are focussing on the later phases of the industrialisation of a design idea. However if this site is for education its crucial that you also work on visualising the earlier processes - Idea creation - How a designer understands/ the analysis of a need to create a design solution in the first place. Becoming informed is crucial. Defining a real need is crucial to the potential success of any design. Leading products, brands and companies understand this focus. Therefore developing relevant filters is crucial early in a creative process. Your PhD study should make clear that design is not a science and design processes do not necessarily lead to design innovation. Also design does not work in isolation - it is about working with many disciplines. It is the idea and design sensitivity combined with the appropriate level of investment to bring the idea to market - to the eventual end user which is crucial. Only a few leading companies understand this. How to satisfy future desires from today's needs. A designers role is to be sensitive to these desires and search for relevant solutions. The role of technology innovation linked to a design solution is fundamental. Technology is the enabler/barrier and

enables new innovations to evolve over time. Good luck with the survey and I look forward to seeing the end results. Roger

Respondent 77: One thing I felt was missing was the very important stage of research. It does not seem accurate to me that the industrial design process should start with the "concept" stage. From my personal experience, more than half of the total amount of time given to an industrial design project is spent on research. Quite a good website, I might recommend it to undergraduates. I do think, however, that the title of each page should appear on the top rather than on the lower right corner. Congratulations!

Respondent 78: Too many links-images-explanations 'jumping' within the same page, sometimes you feel you have no space 'to rest'

Respondent 81: Keep the graphics simple. Concentrate on ideas first before adding any animations as these often can detract from the main messages

Respondent 83: Sort of looks like you're building an ontology of processes and tools...if the intent is to show how tools facilitate or otherwise influence certain aspects of design processes, then it is hinted at here.

Respondent 84: Hi Great work, please visit my site about sustainable design, it has many links that could be helpful for you, specially "design research" with many sources (right side of the site). If you want I can include your site as well. <http://marciodupont.blogspot.com> Best, good luck!

Respondent 85: I am going to use this to help explain how the process should be done. The Converge/Diverge Wavelength is a little vague but still works.

Respondent 86: Please do state it clearly that the 'design process' referred to here is just one portion of a much longer and wider process. Prior to studio work, any designing activity (should) starts with a thorough research, not necessarily conducted by studio designers. Then there is a need for Studio Design researchers, working side by side with studio practitioners. And finally there is also a need for after studio Design researchers on the live (until "grave" time) of the designed outcome. Of course all research findings at different stages being fed to ultimately ameliorate work of studio designers with/and their various tools.

Respondent 87: load pages faster

Respondent 91: The site seems a bit complex at first (and perhaps the design process is over-categorized?). Could possibly be simplified, but still allow for diving into details?

Focus Group of IDsite validation: Results for Question 5, feedback.

Q5. Finally, please use this space to provide any further observations or suggestions to help us improve IDsite?

Student 1: I can't see the pictures so I can see them big.

Student 2: Very helpful tool, would be nice if you could click on images to enlarge them.

Student 3: Clear, good use of colour and explaining process effectively, possibly room for more explanation to process.

Student 4: It is a really interesting web. Including many information, But it is a bit crowd. Too many things happening in one once. Overall, it is a good idea and nice web. Good luck for everything. Looking forward to see its future version.

Student 5: I really like this website. I think it also gives people who don't really know what ID is a very good understanding of ID. The different parts are good explained (also visualisation) and shows how design processes work

Student 6: Great site very clear with a lot of information of ID. Nice layout. Sometimes

confusing by clicking right and looking left. Buttons are too close together possibility of wrong clicking.

Student 7: The pages are quite busy & make it hard to focus on what you actually need to read. There could be more links/detailing regarding processes.

Student 8: Nice layout and interaction but sometimes hard to know where to start looking. Some images are unclear, this may be just because they are quite small. The indicator bars are useful & an interesting design, easy to see what they are showing and get a quick summary

Student 9: Maybe some more, larger visual examples so that we can see progress at different points.

Student 10: A bit too much writing. Nice to see sketches & renderings. Not overly sure where to look and how to navigate

Student 11: The general website's graphics are too complicated. Personally would have preferred it with more interesting and writing that way. The general website could be done in a simpler way.

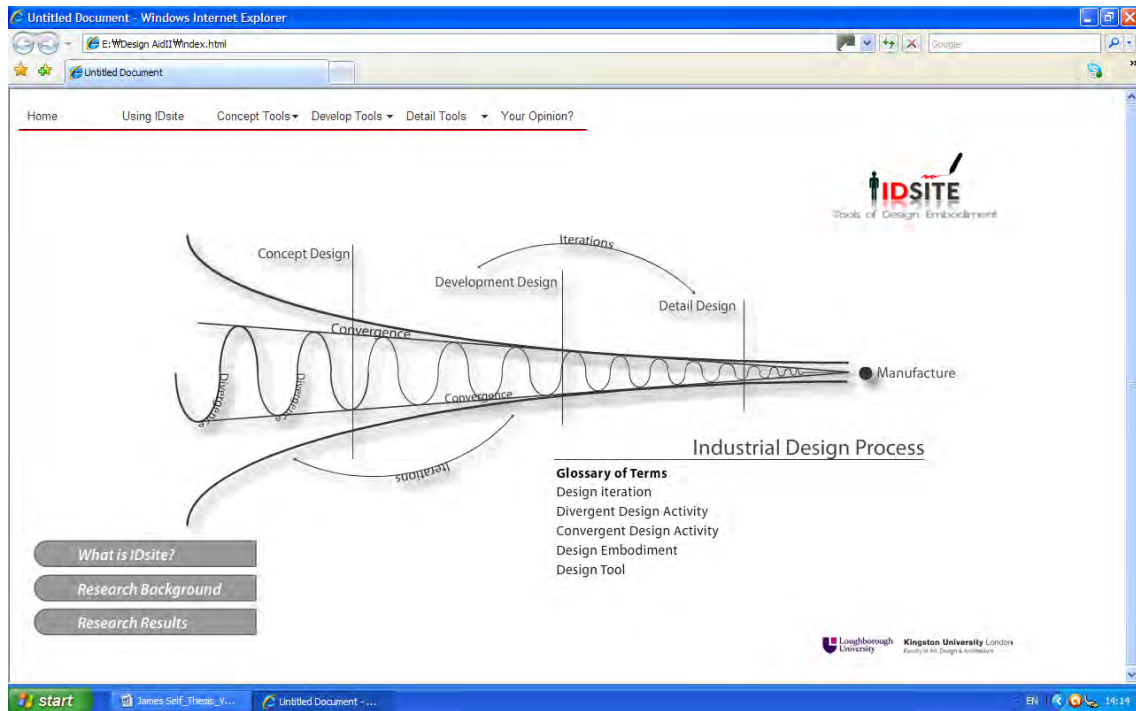
Student 12: It is hard to navigate around once you have clicked on the sub headings at the top. The colours are also quite 'school like' not very exciting, gives the impression that ID design is boring and prescriptive.

Student 13: On the website I found it hard to know what is where. Not that clear. But seems helpful when you find what you want.

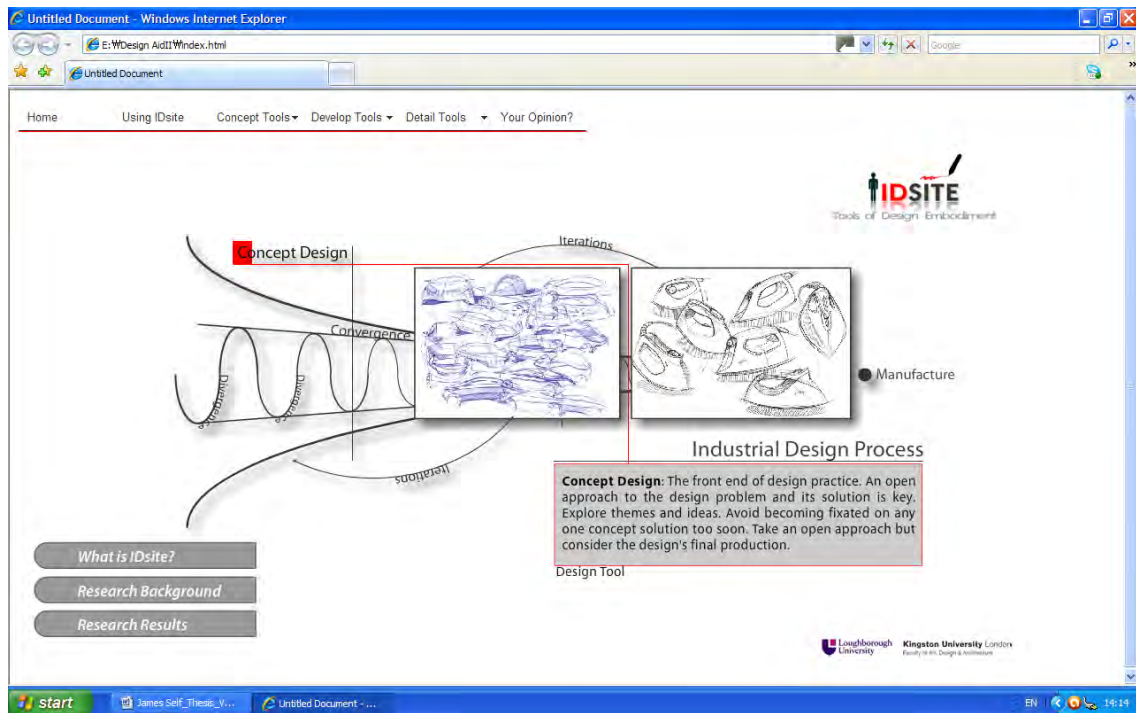
Student 14: It's a bit cluttered, a simpler interface and easier to read graphic would be amazing.

Student 15: This illustration (sketch of model) might need slightly more explanation for non-designers to understand.

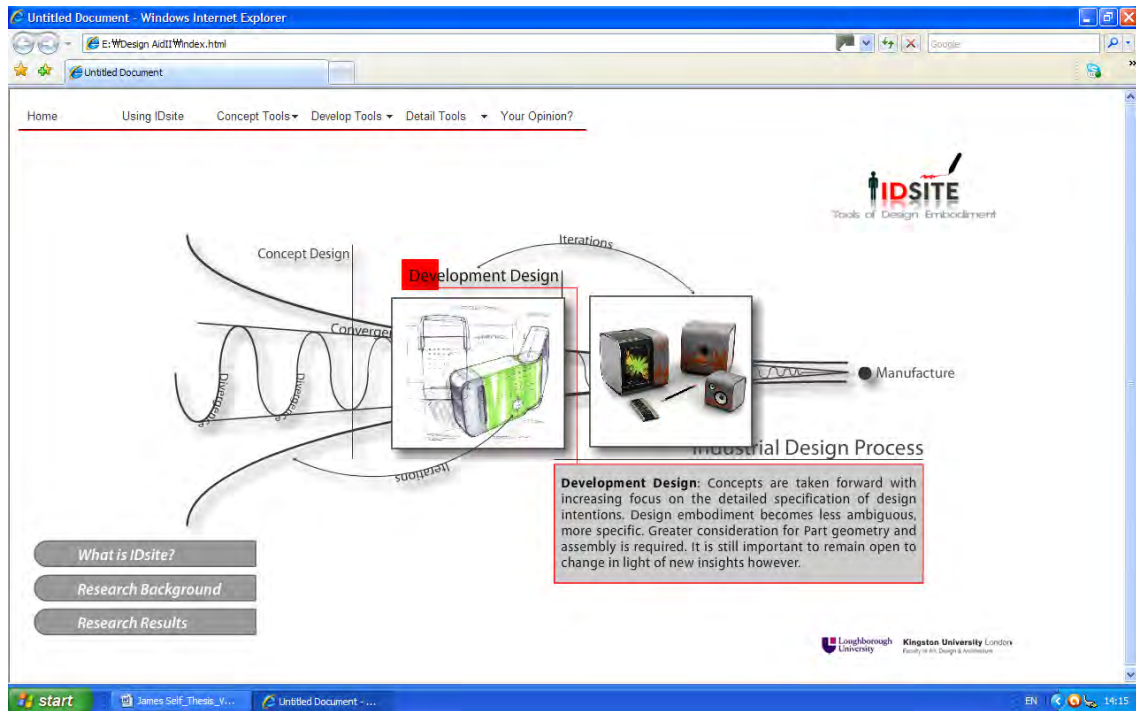
Appendix N
Set of IDsite plates



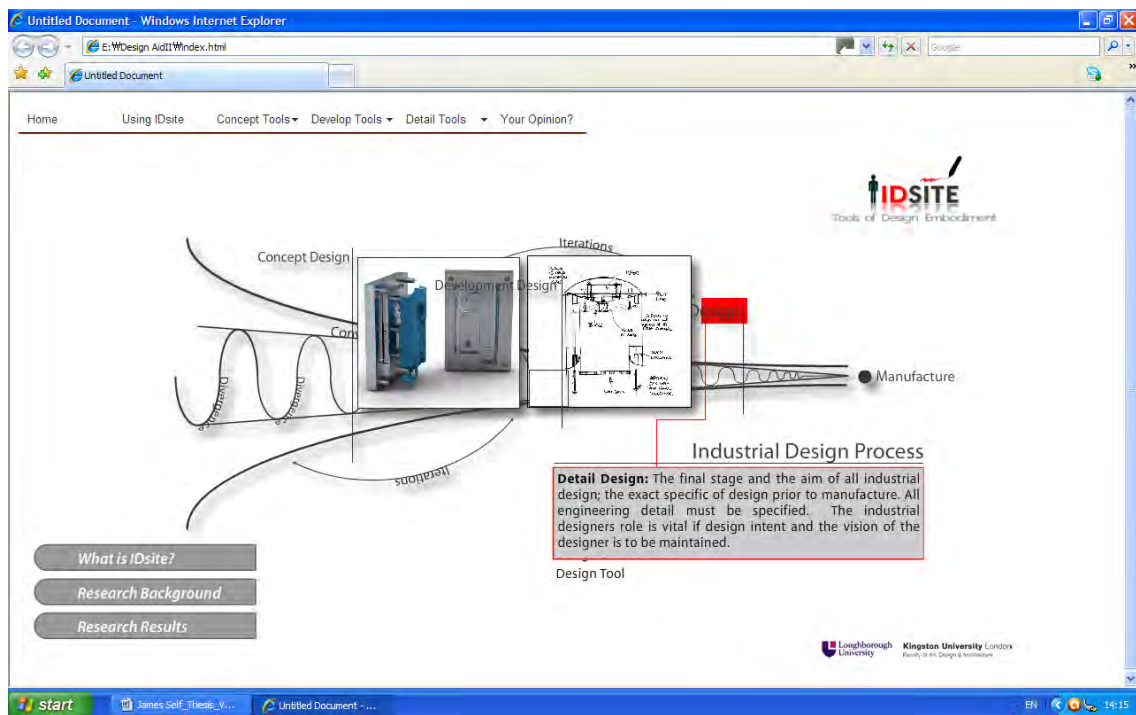
Home page



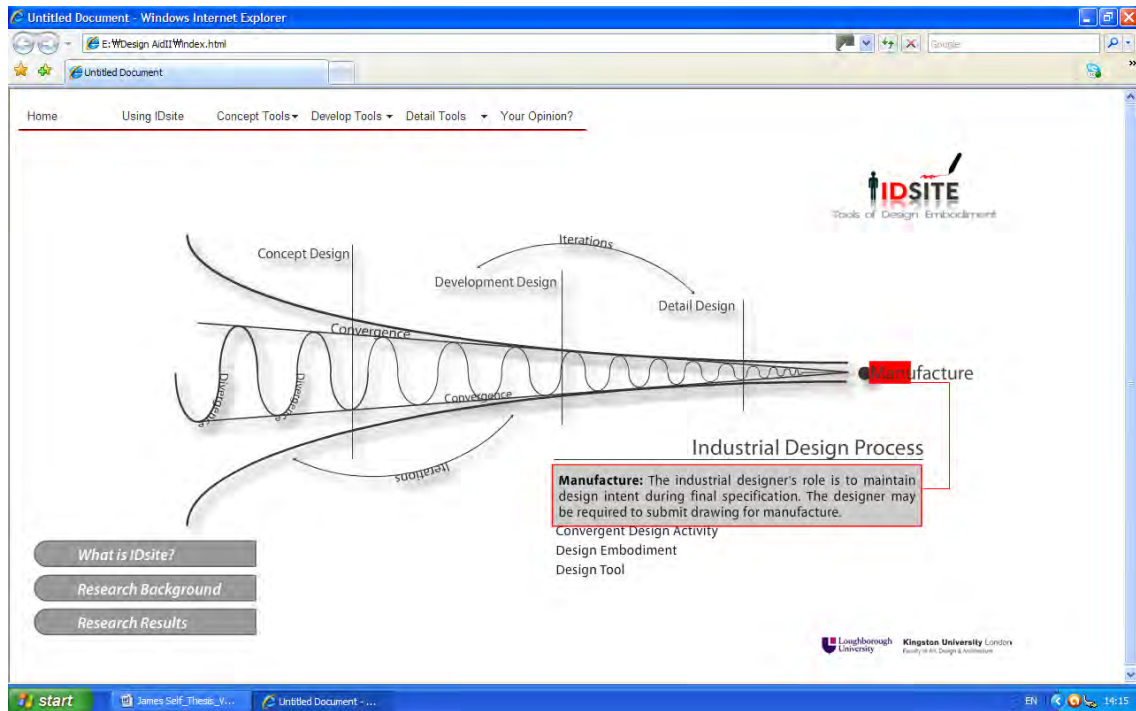
Home page over 'Concept Design'



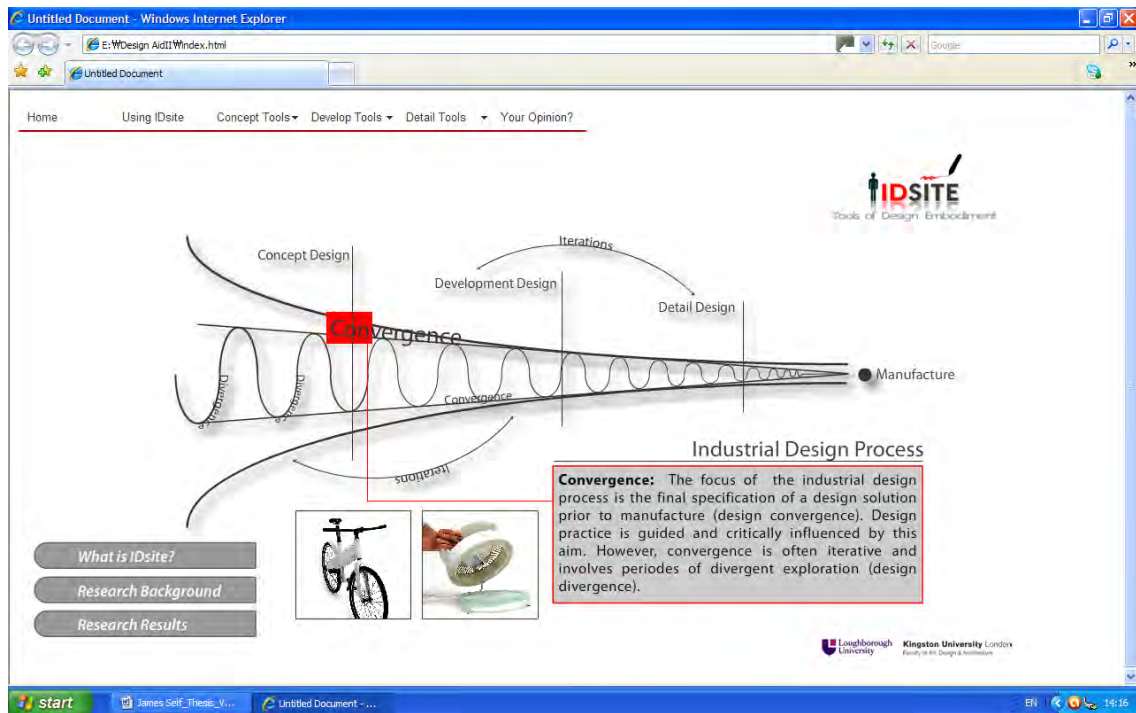
Home page over 'Development Design'



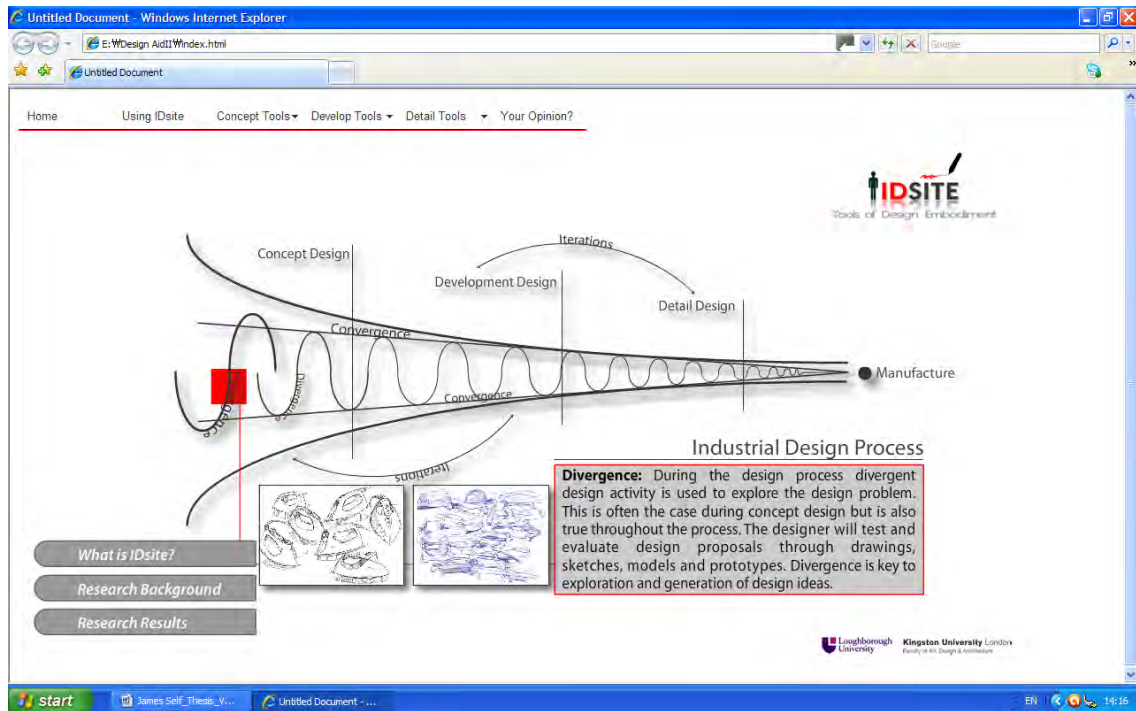
Home page over 'Detail Design'



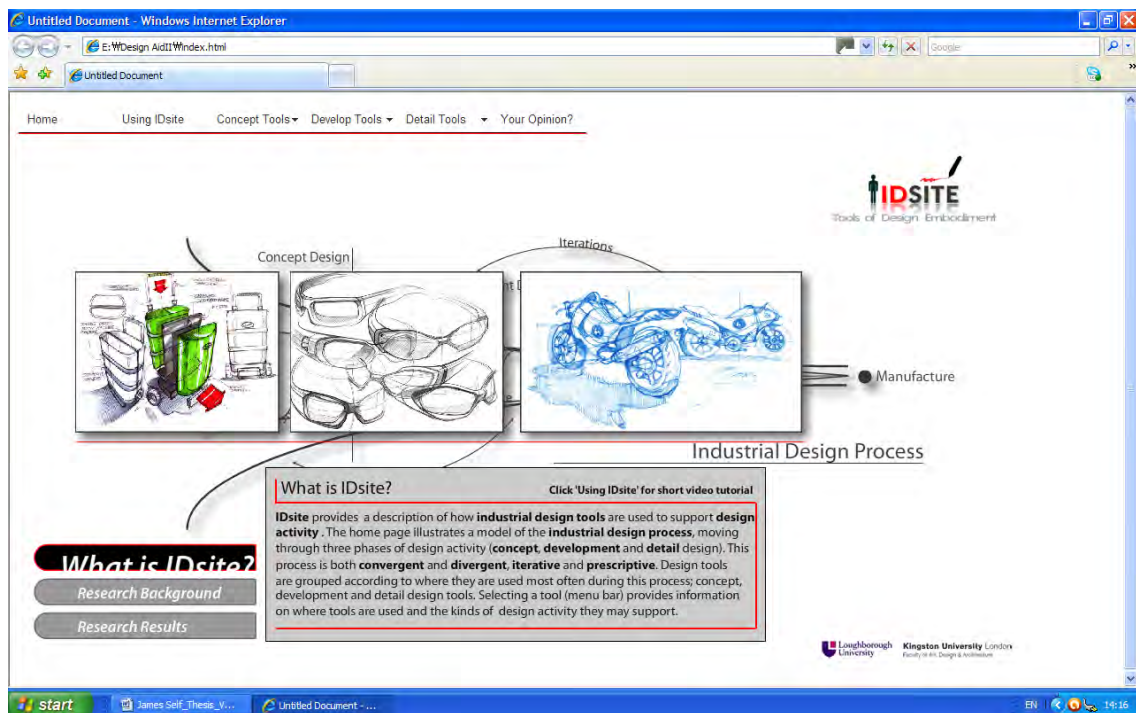
Home page over 'Manufacture'



Home page over 'Convergence'



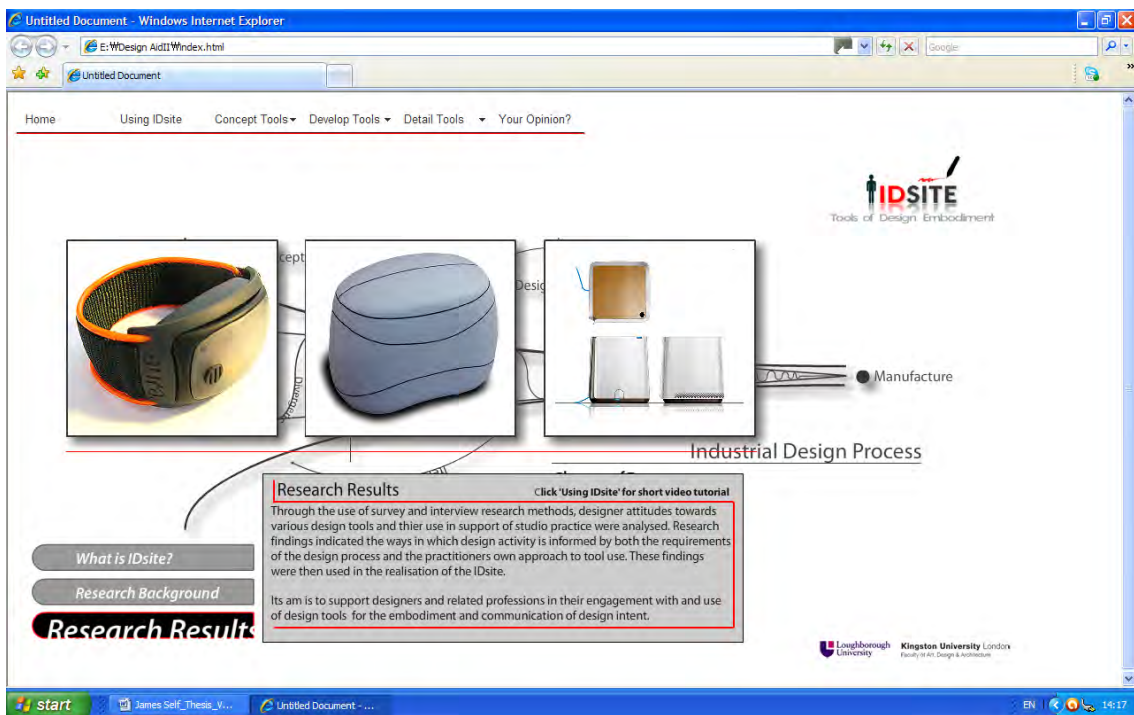
Home page over 'Divergence'



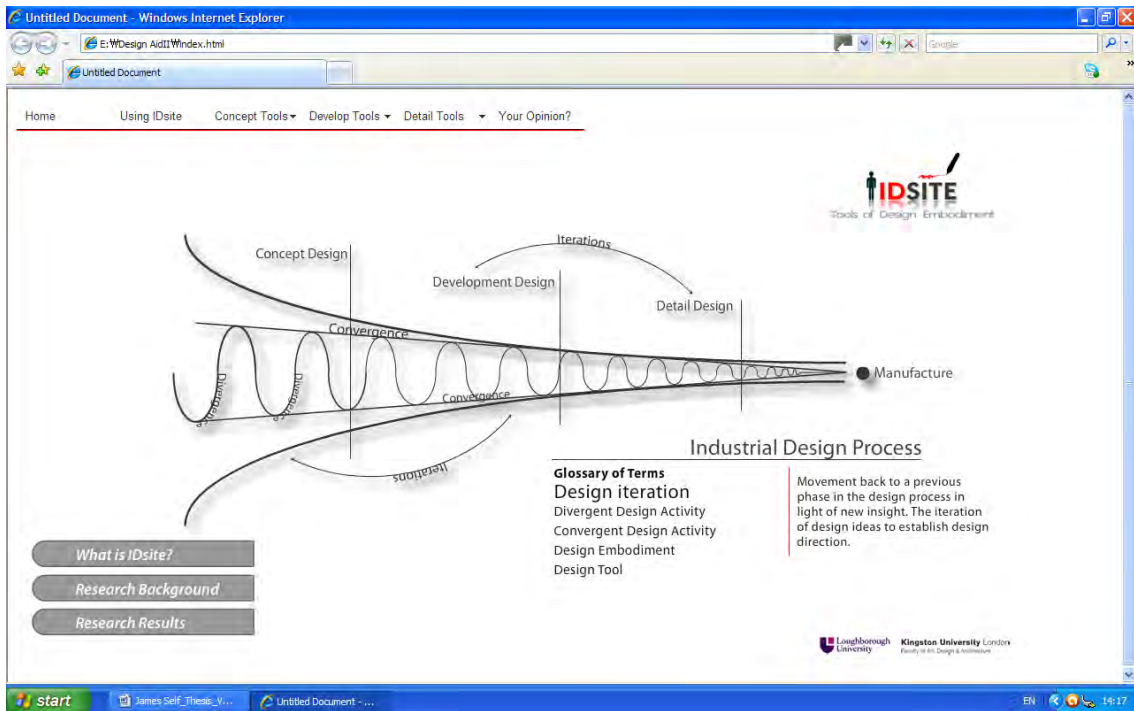
Home page over 'What is IDsite?'



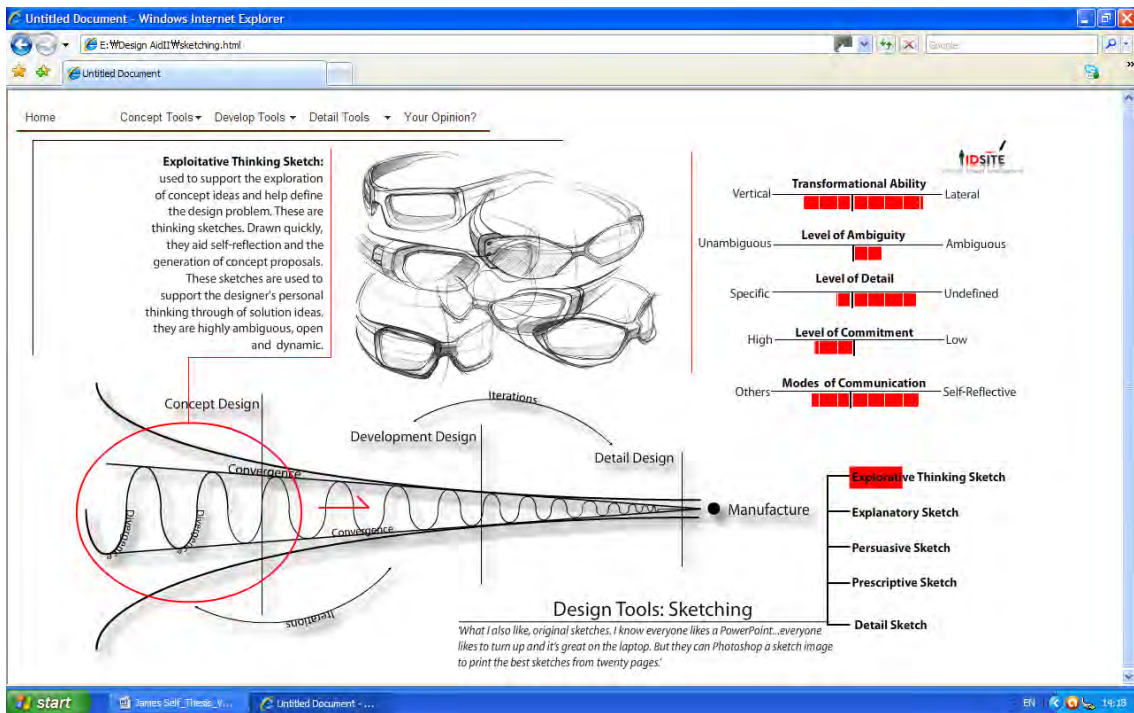
Home page over 'Research Background'



Home page over 'Research Results'



Home page over 'Glossary of Terms'



Tools page, 'Sketching'

Digital Sketching: The versatility of digital sketching, like its conventional counterpart (see sketching), may be used throughout the design process. The digital media is readily transferable between other digital tools. However, like all tools, the character of digital sketching will influence the embodiment of design ideas. Features, such as the 'undo' button bring great affordances, but its use, for example, must also be considered in terms of its effect on fluid embodiment and reflection. Like all tools, the digital sketch is most effective when used to achieve an outcome in the context of a wider studio practice, rather than designing to the tool's ability.

Design Tools: Digital Sketching
"You have to learn, almost another programme, I think that's right. It's not intuitive enough maybe..."

Category	Scale	Value
Transformational Ability	Vertical - Lateral	Vertical (5 red squares)
Level of Ambiguity	Unambiguous - Ambiguous	Unambiguous (1 red square)
Level of Detail	Specific - Undefined	Specific (3 red squares)
Level of Commitment	High - Low	High (2 red squares)
Modes of Communication	Others - Self-Reflective	Others (4 red squares)

Tools page, 'Digital Sketching'

Explorative Sketch Models: used to support the exploration of concept ideas, design embodiments as sketch models allow the designer to quickly explore the physical form of design intentions. Sketch modelling, critically, begins to allow the evaluation of conceptual solutions in a physical form during conceptual design practice.

Design Tools: Sketch Modelling
Explorative Sketch Models
Explorative 'Ad hoc' Sketch Models

Category	Scale	Value
Transformational Ability	Vertical - Lateral	Vertical (5 red squares)
Level of Ambiguity	Unambiguous - Ambiguous	Unambiguous (1 red square)
Level of Detail	Specific - Undefined	Specific (3 red squares)
Level of Commitment	High - Low	High (2 red squares)
Modes of Communication	Others - Self-Reflective	Others (4 red squares)

Tools page, 'Sketch Modelling'

The screenshot shows a web browser window displaying the 'Tools page, 3D CAD'. The page layout includes a navigation bar with 'Home', 'Concept Tools', 'Develop Tools', 'Detail Tools', and 'Your Opinion?'. The main content area is divided into several sections:

- Explorative CAD Modelling:** A text block explaining that this tool is used to support the exploration of concept ideas and help define the design problem. It notes that design activity is less specific and more ambiguous, leaving more room for divergence and iteration.
- Visuals:** Several 3D CAD models of a component are shown in various orientations.
- Design Process Diagram:** A funnel-shaped diagram illustrating the design process from 'Concept Design' to 'Development Design' to 'Detail Design' and finally to 'Manufacture'. It includes labels for 'Iterations' and 'Convergence'.
- Design Tools: 3D CAD Modelling:** A list of tools including Explorative CAD Modelling, Explanatory CAD Modelling, Persuasive CAD Modelling, Prescriptive CAD Modelling, and Detail CAD Modelling.
- Measurement Scales:** Five scales are provided: Transformational Ability (Vertical to Lateral), Level of Ambiguity (Unambiguous to Ambiguous), Level of Detail (Specific to Undefined), Level of Commitment (High to Low), and Modes of Communication (Others to Self-Reflective).

The browser's address bar shows the URL 'E:\WDesign Aids\W3D_Dig_CAD.html'.

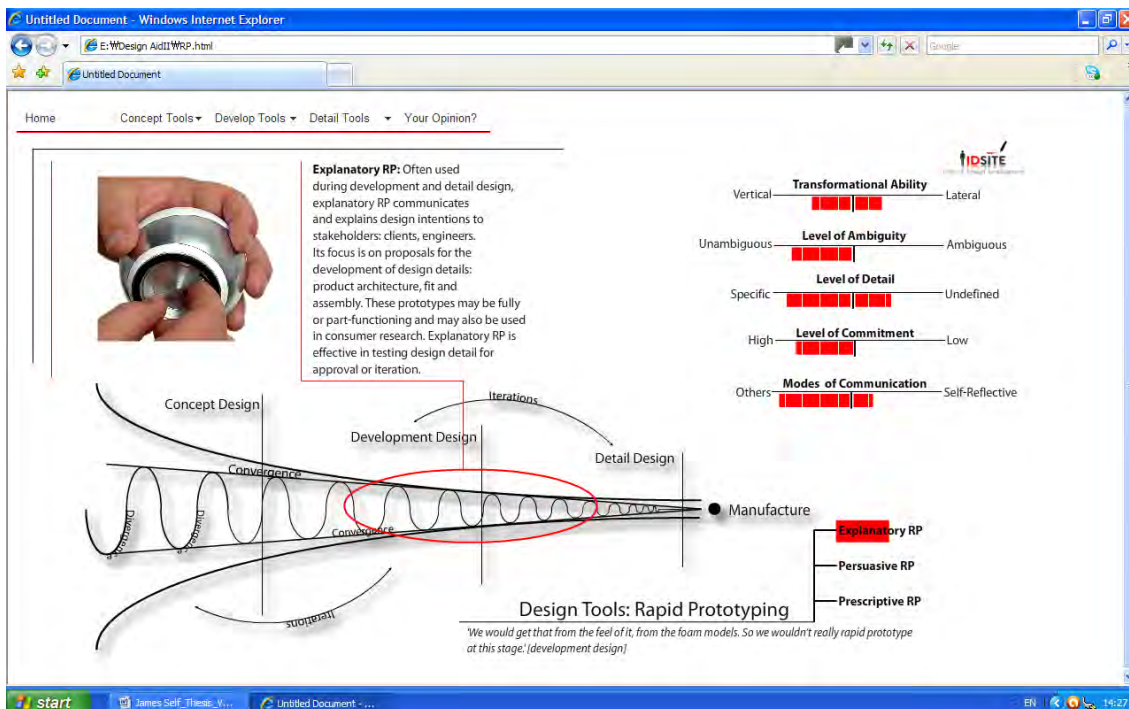
Tools page, '3D CAD'

The screenshot shows a web browser window displaying the 'Tools page, 3D Printing'. The page layout is similar to the 3D CAD page, with a navigation bar and a main content area:

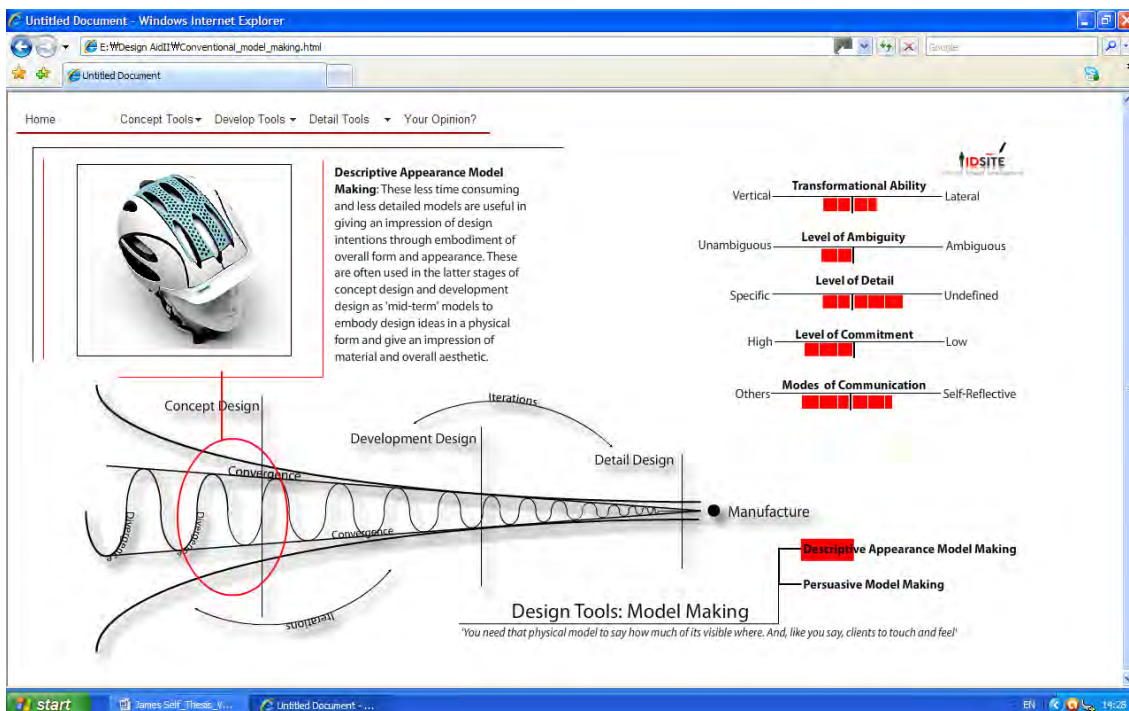
- Explorative 3D Printing:** A text block explaining that this tool is used to support the exploration of concept ideas, design embodiments as 3D Prints offer a quicker, more cost effective alternative to RP. It notes that prints are used to embody and explore concept ideas in a physical form during concept design.
- Visuals:** A 3D printed part and a 3D CAD model are shown.
- Design Process Diagram:** A funnel-shaped diagram illustrating the design process from 'Concept Design' to 'Development Design' to 'Detail Design' and finally to 'Manufacture'. It includes labels for 'Iterations' and 'Convergence'.
- Design Tools: 3D Printing:** A list of tools including Explorative 3D Printing and Explanatory 3D Printing.
- Measurement Scales:** Five scales are provided: Transformational Ability (Vertical to Lateral), Level of Ambiguity (Unambiguous to Ambiguous), Level of Detail (Specific to Undefined), Level of Commitment (High to Low), and Modes of Communication (Others to Self-Reflective).

The browser's address bar shows the URL 'E:\WDesign Aids\W3D_Printing.html'. A quote at the bottom of the diagram reads: "It's quite time consuming. Say, to print out maybe a cordless telephone handset. That will take about ten hours to print".

Tools page, '3D Printing'



Tools page 'Rapid Prototyping'



Tools page, 'Model Making'

Explanatory CAD drawing:
Used to explain detailed and specific design intentions, design activity is concerned with the final definition of design intentions during detail design. To finally confirm solution(s) to the design problem for manufacture.

Transformational Ability
Vertical Lateral

Level of Ambiguity
Unambiguous Ambiguous

Level of Detail
Specific Undefined

Level of Commitment
High Low

Modes of Communication
Others Self-Reflective

click...click

Design Tools: CAD Drawing
 Explanatory CAD Drawing
 Prescriptive CAD Drawing

"We shell all our models. So, wall thickness. So all our data gets shipped to the manufacturer. All they have to do is add in the engineering detail."

Tools page '2D CAD Drawing'

Appendix O
IDsite

Summary

This appendix presents a design tool (IDsite) to disseminate research results to practicing designers and communicate knowledge of design activity and tool use. Dorst (2007) discusses a need for design research to engage practice and provide a stronger platform from which research may be conducted:

We [design research] need to re-engage with practitioners, and get involved in experiments within the rapidly changing design arena. Design researchers should join design practitioners in co-creating the design expertise and design practices of the future.

(Dorst 2007 p11)

IDsite attempts to provide a platform for understanding the rich and complex activity of industrial design; how the use of tools and the designer's own idiosyncratic approach has an influence upon design activity during studio practice; and the final specification of design intent. IDsite's approach to research dissemination has the potential to facilitate improved engagement with a practice orientated audience. Whilst acknowledging the role of more conventional methods of dissemination, more relevant approaches to the articulation and exchange of design research knowledge are required. These approaches call for innovation in knowledge dissemination that exploits the highly visual language of design in order to engage practice.

A literature review was conducted of existing attempts to engage a practice-based audience through novel approaches to design research dissemination. After this review, the design of IDsite is presented. This is followed by a pilot study of the site with a group of design practitioners. A beta version of IDsite is discussed. The chapter then presents IDsite's validation through two studies aimed at testing its effectiveness as a tool to support design practice. The first phase of validation involved a survey of 94 designers and related professionals. A second validation study used a focus group of 20 undergraduate students. Like the designers, students were asked to assess the effectiveness of IDsite in supporting understanding of design tool use during the design process. The chapter ends with the analysis and discussion of results.

Existing Design Tools

The research into typologies of design tools that may prove useful for designers produced a short review of existing design tools resulted in the identification of four tool paradigms:

1. Physical card based design tools
2. Database and system design tools
3. Web tutorials, blogs and discussion forums
4. Printed 'how to' texts

These four design tool types are presented below in terms of their success to date in supporting design practice.

Physical Card Based Design Tools

Card based design tools use a system of physical cards to support design practice. Much like regular playing cards, they are often small and portable, allowing the practitioner to carry them for easy reference when required. Three card based design tools were identified within the literature: the IDEO Method cards aimed at supporting designers in their approach to design problems (IDEO 2010); Lockton's DwL (Design with Intent) cards that suggest techniques to help fulfill design requirements (Lockton, Harrison et al. 2010) and Pei's et al (2008) CoLab card sets to promote understanding between industrial designers and engineers.

IDEO Method Cards

The IDEO Method Cards embody the empathic, human centred approach to design as a philosophy of the design firm that created them (IDEO). The set represents a wide range of skills and experiences, gained over many years, that IDEO use to inform their approach to studio practice. The cards describe the ways these ideas may help designers create more usable and delightful designs through approaches to understanding human needs. The 51 cards are divided into four sets with each set describing the different ways in which a designer may empathise with people:

- Through analysing collected data, the 'Learn' set
- By observing peoples behaviour, the 'Look' set
- Through direct dialog with people and by eliciting information that might be relevant, 'Ask'
- The 'Try' set that describes ways to simulate user experiences to promote empathic understanding.



Figure 1 IDEO Method cards showing from image and back explanation

Each card is double faced with the images on each card reinforcing the suggested design practice. The IDEO cards illustrate the communication of design knowledge through embodiment in a way that makes knowledge more relevant to the practicing designers studio practice. However, despite an extensive search, the researcher was unable to find research on the card's validity. It is unclear to what extent the cards are being used to support industry.

Lockton's et al's Dwl (Design with Intent) Card System

Lockton's Dwl system employs a set of cards to help designers develop strategies to influence user behaviours (Lockton, Harrison et al. 2010). Lockton describes the role of the Dwl system as providing designers with a set of principles to help influence the user of a product or system towards a target behavior. The Dwl is a 'tool of suggestion' (ibid), where influencing user behaviour is important to the operation of a product or system. Like the IDEO Methods tools (Op cit), the Dwl cards aim to embody theoretical principles in a way that may be more accessible to practicing designers. The cards, like IDEO's, support designers through their description of ideas and practices in a more engaging and relevant way, using both text and contextual imagery.

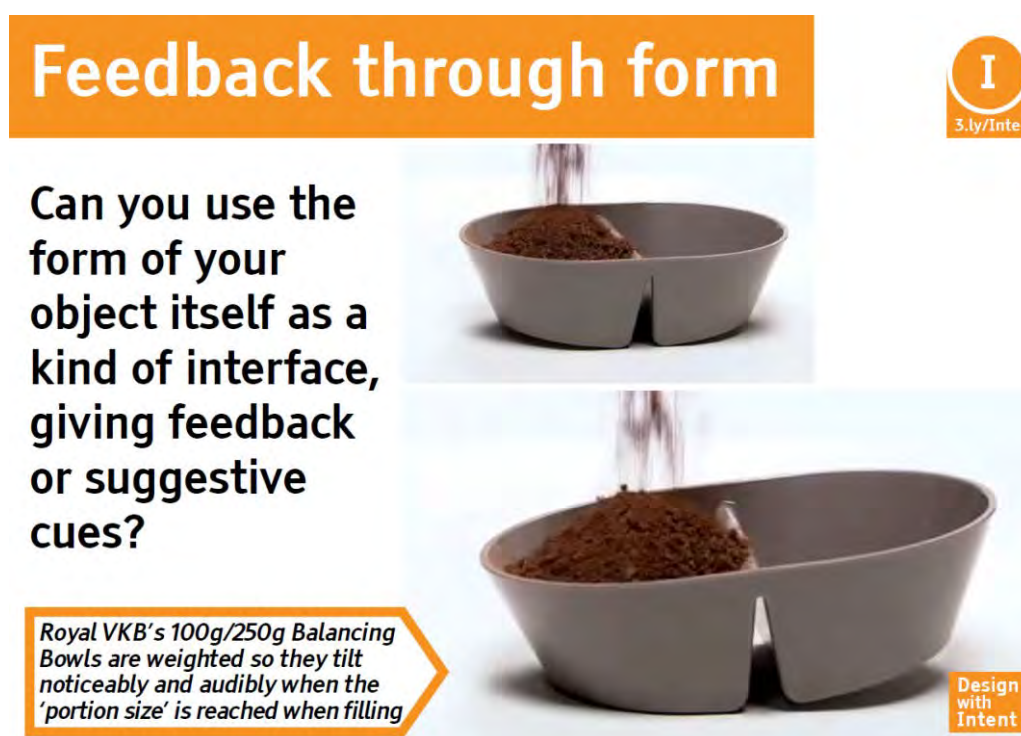


Figure 2 Example card showing opportunity for improved user feedback through embodied interaction

Pei et al's CoLab ID and ED Collaboration Card system

Pei's CoLab system was designed to address a need to support collaboration between industrial design and engineering design practitioners. Pei's doctoral study (2009) identified the different approaches the two disciplines take when discussing the

development of design ideas. Confusion over the ways in which the two professions discussed design representations resulted in the taxonomy of terms of reference used by the two groups to describe design representations. This knowledge was then embedded in two sets of design cards, one for each of the two disciplines. Validation suggested the system is effective in supporting better understanding between industrial and engineering designers.

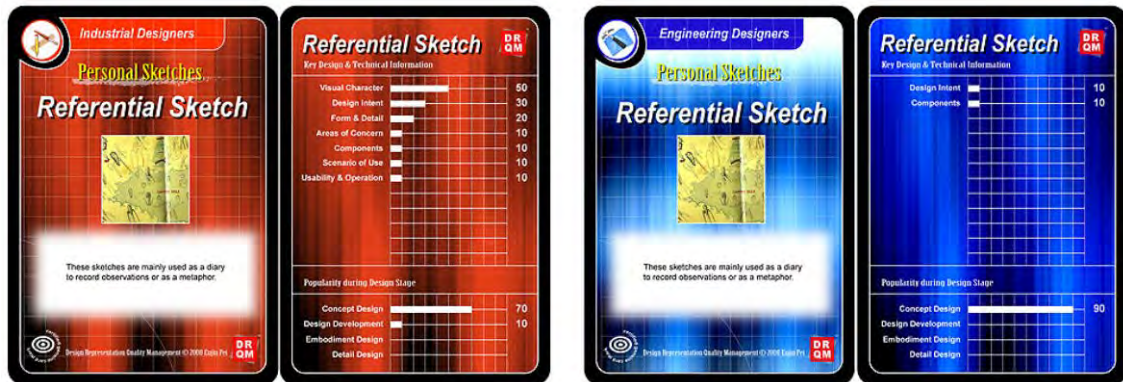


Figure 3 Examples of the CoLab system showing representations used by industrial and engineering designers

Like the IDEO Method cards and the Dwl toolkit, Pei's et al (Op cit) CoLab system aims to provide practitioners with an accessible and usable way to understand the theoretical principles that underpin their creation, 'The information [design representation in practice] was indexed into CoLab cards that would enable the two disciplines to gain joint understanding and create shared knowledge'.

A validation study at the end of Pei's thesis (Op cit) suggested the ability of CoLab to support understanding between designers and engineers. The use of some or all of these card-based systems may be effective in engaging practitioners and supporting their studio practice. However more research is required to assess their impact within the design industry.

Database and System Design Tools

A review of design tools identified two database tools, both used through digital interfaces. Almendra & Christiaans (2009) design decisions support tool (DM Tool), aimed at supporting design practitioners in their decision making process through a system of monitoring and recording. And Bin Maidin's et al Design for Additive Manufacturing Repository (DfAM), developed to assist industrial designers in their understanding of additive manufacturing techniques and support design for AM during concept design.

Almendra & Christiaans's DM Tool

The aim of the DM tool was to support the designer in their critical appraisal of their own decision making processes. In order to achieve this Almendra & Christiaans (Op cit) created a folder based tool that allows student designers to record design decisions as they worked through a design process. The aim was to facilitate a more critical level

of engagement by providing a recording of the moves the student designer would take through the process. The DM tool is split into four different areas to record design decisions: information access, use, idea generation and process (Figure 4):

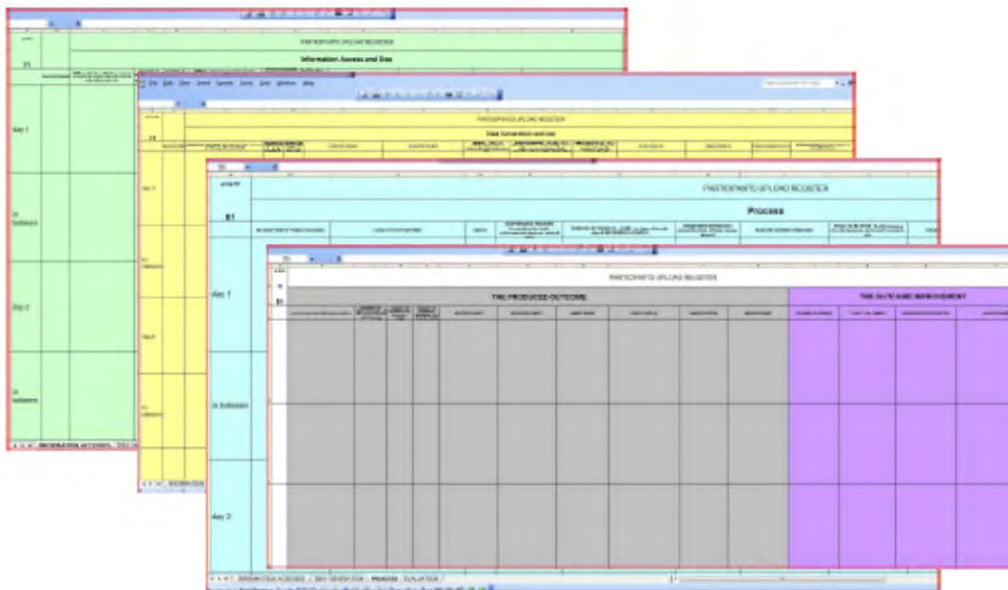


Figure 4 Almendra & Christiaans's DM Tool to support critical reflection during design process

However, in an experiment to test the tool's ability to develop a more critical engagement with practice, Almendra & Christiaans's (Op cit) admitted it's limitations in terms of its use in an often dynamic, fast-moving process of design development.

Design for Additive Manufacturing Repository (DfAM)

The DfAM additive manufacturing repository aims to support industrial designers in assessing, during conceptual design, the suitability of additive manufacture as a means of production. The DfAM tool guides designers through a series of questions to describe the kinds of design features available for a given concept based upon the designer's previous input data. The design tool attempts to support the designer's conceptual design through a better understanding of the ways in which rapid prototyping affordances may help influence conceptual design development. The aim, like that of the card-based tools, was to communicate design knowledge in an accessible and relevant way. Like the other design tools discussed above, Almendra & Christiaans's DM tool, the Dfam repository uses visual examples to help communicate information (Figure 5):



Figure 5 The DfAM repository, screen showing reasons for the use of additive manufacture

Web Tutorials, Blogs and Discussion Forums

A number of weblogs and forums have emerged as venues for discussion of practice and the sharing of skills and knowledge (Nugent 2010, Core77 Online Industrial Design Magazine2010). These forums continue to attract attention from practitioners, students and design educators alike, offering practical advice and guidance through multi-media tutorials, articles and discussion forums.

Core77 Industrial Design Magazine & Resource

Founded in 1996 Core77 is a growing web-blog aimed at the industrial design practitioner, students and related professionals. The blog continues to expand, providing a venue for discussion as well as the publication of articles from design practitioners and thinkers (Norman 2011). Core77 is structured around a windows' based navigation system with the extensive use of images and some multi-media content. While not a design tool in the sense of the physical cards and database systems, Core77 describes itself as a resource for the sharing of knowledge, ideas and skills throughout an international industrial design community (Figure 6):



Figure 6 Screen shot taken from Core77 homepage

The site has a variety of discussion forums, some with direct relevance to the study (Design Sketching, CAD Tools and Design Research). Designers find Core77 useful in discussing approaches to studio practice. Indication of this is seen in the site's active discussion forums. Most interesting is the way the unstructured nature of 'help' available in these forums allows ideas to be proposed and considered by a variety of individuals. A study of the impact of such sites within studio practice would be most interesting, none was found however.

ID Sketching

Idsketch.com, like Core77, is a web-blog established by an American industrial designer, Spencer Nugent (Nugent 2010). Idsketch disseminates the author's skills in design embodiment through video tutorials, workshops and advice columns. Drawing and sketching tutorials provide step-by-step instructions through examples and guidance on style and technique. Practitioner work is posted to the site providing an on-line gallery.

Like Core77, the focus is on community and the provision of an online environment where ideas may be exchanged and knowledge and skills disseminated. Content and publication is controlled by a team of moderators who act as editors, controlling content and establishing direction. Figure 7 illustrates a video tutorial:



Figure 7 Sketching tutorial, Spencer nugent, idsketching web-blog

Due to its bias for tutorial and the dissemination of skills related to design embodiment, idsketching has relevance to this research. However, idsketching presents information on the pragmatic application of tools and processes in support of studio practice. Little was found of the discussion of or engagement with the issues, theories and principles that underpin the choice and use of tools during practice.

Printed 'How To' Texts

A number of texts have been published on the use of design tools in practice. One of the earliest is Powell's *Presentation Techniques*, published in 1980 (Powell 1985). In his book Powell introduces the role of drawing in design through a short history of industrial design and the use of design tools to embody and communicate design intent. The text proceeds through a variety of analog drawing and presentation tutorials supported through by example graphic illustrations.

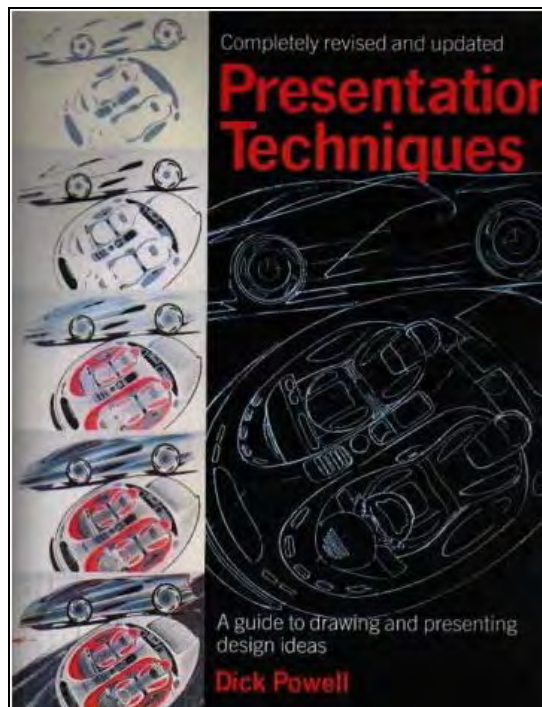


Figure 8 Powell's illustrated 'how-to-' guide of conventional graphic illustration

Pipes text, 'Drawing for Designers' (2007) describes a variety of tools and processes aimed at supporting designers in their use of tools. Pipes (2007) structures his discussion around examples to link the use of a variety of design tools to various stages in design practice.

The text 'Design Sketching', written by two graduating industrial design students at Umea Institute of Design in Sweden (Olofsson & Sjolen 2006), illustrates design sketching techniques. However, unlike other books of the same paradigm, Design Sketching uses a taxonomy of sketch types to describe their role in supporting the requirements of the design process: detail sketch, explanation drawing for example. Olofsson and Sjöln (ibid) attempt to describe best practice approaches to design embodiment and communication, and relate the use of design tools to the requirements of practice. Figure 9 illustrates the ways Olofsson and Sjolen juxtapose images with text in order to explain the various ways sketches may be used to embody design intent:

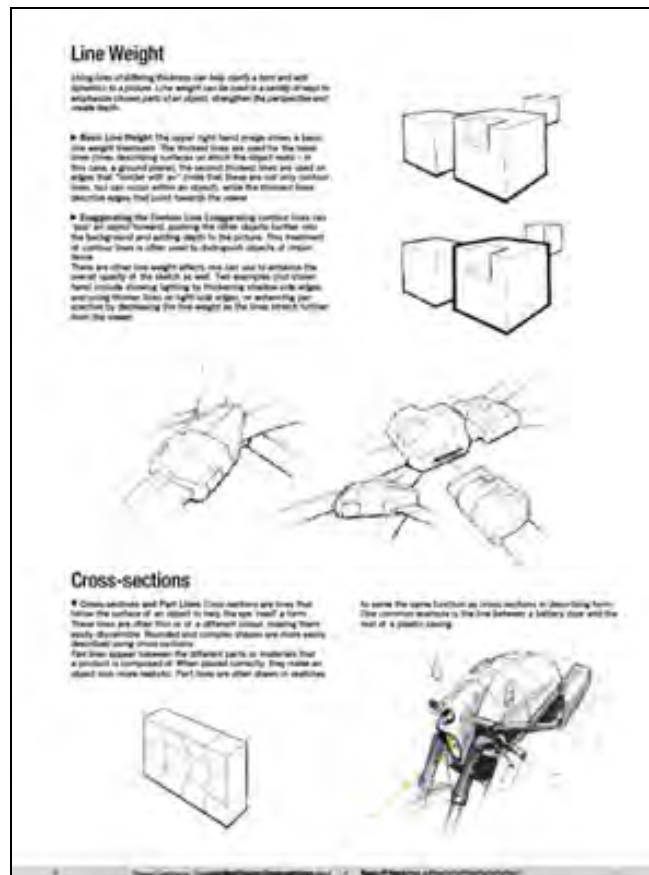


Figure 9 Olofsson & Sjolen's text on design sketching

In this section physical card based systems, database and system design tools, Web tutorials & design blogs and printed, instructional texts have been discussed. The use of graphics and imagery to help communicate principles was common to all. It was noted that none of the reviewed design tools directly addressed relationships between the use and effectiveness of design tools, the influence of practice and the designer's own skills and expertise, the subject of this research.

Development of the Design Tool (IDsite)

The development of a design tool to support practitioners was undertaken in an attempt to address Research Question 4 (Chapter 1):

4. How might research findings be best communicated to practicing designers to foster a more critical engagement with design tools?

The challenge of bridging the gap between design research and its pragmatic application within studio practice is identified in design research (Dorst 2007). Like existing design tools, the objective was to engage practitioners and students of design through dissemination that exploits the highly visual language of design in order to best engage practice.

Primary research indicated that less experienced designers engaged with and used design tools differently compared to more seasoned practitioners (Thesis Chapters 7

and 8). Results suggested this difference is linked to working methods related to levels of expertise. Students tend to fixate and attach to the design concept sooner; tending towards the convergence of design ideas to arrive at a final design outcome. Practitioners, on the other hand, tend to remain more open to divergent iteration for longer. Their design work is characterised by a more open and dynamic approach. Results also indicated the use of certain design tools may compound these existing working methods. A tendency to converge design intentions sooner was heightened through engagement with particular tools compared to more experienced practitioners.

The aim of the design tool was to provide practitioners, particularly less experienced students and novice designers, with a more critical understanding of how the choice and use of design tools may influence their studio practice. The objective was to support design practitioners by providing an enhanced awareness of the role tools play in influencing studio practice, and providing an opportunity for practitioners to reflect on their own approach when using design tools. The following criteria were drawn up to inform the design of IDsite and would be required to:

1. Illustrate a three stage model of industrial design practice (concept, development and detail design).
2. Demonstrate the requirement of design practice to progress design intentions towards a final solution to the design problem.
3. Provide a description of design practice as a process that iterates between stages with periods of convergent progression and divergent exploration.
4. Contextualise the use of design tools within design practice, highlighting the critical relationship between tool and practice.
5. Illustrate where, typically, tools of various kinds are used to support practice.
6. Articulate tool effectiveness in support of relating the UTCs of tools to the requirements of practice.
7. Engage the audience through the presentation of knowledge in a way that is immediately accessible and relevant to studio practice.

The review of existing design tools defined the model that may be possible and suggested that a card based approach is a popular means of engagement with practice (see above). However, it was decided that a web based, interactive approach would have many advantages. Firstly, publication through web-hosting was more cost effective. Second, the researcher wished to disseminate findings to the widest possible audience. Web accessibility affords an opportunity to reach audiences, both domestic and international. Thirdly, given a requirement to include visual images as reference points to aid explanation and also engage the audience, a web-based tool provided an opportunity for the use of multimedia and the layering of information in the form of

images, animation, videos and the provision for discussion and feedback. Moreover, a web-based system would allow for the tool's continued development in light of future research, designer feedback and validation.

The scope for dissemination the web offered, with drastically reduced time-frames in terms of publication, made a web based interactive site an obvious choice. Indeed, of the three non-digital design tools found in the literature, IDEO's Methods cards are available as an application at a reduced cost. Lockton's Dwl (Design with Intent) Card System is being propagated through an online website dedicated to the project and Pei et al's CoLab ID and ED Collaboration Card system is in the process of being converted to digital format for publication in the form of a website.

IDSite: Alpha Version

Adobe's suit of design and web-authoring software was used in the design and publication of an alpha version of IDSite. This section presents screenshots of the site with supporting explanation of its design and intended use.

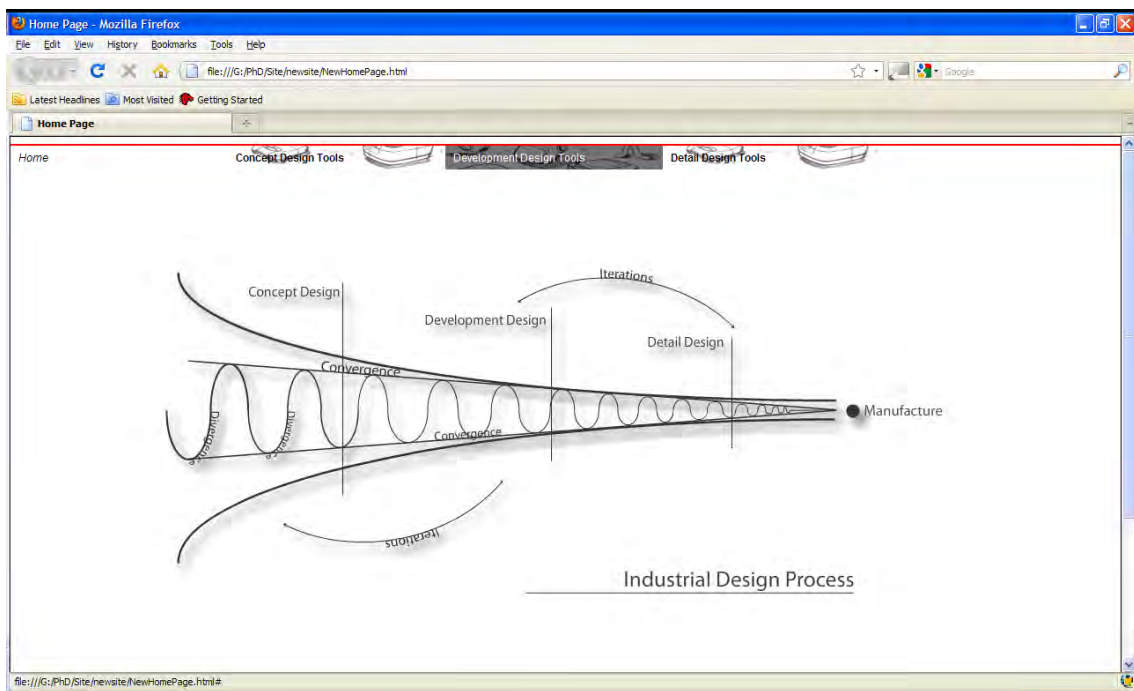


Figure 10 Image of site's homepage

A homepage (Figure 10) presented the user with a simplified model of the industrial design process based upon the model used within this thesis (Chapter 3). Hovering over concept, development, detail design, manufacture, convergence, divergence and iteration displayed information on the model's component parts. Figure 11 is a screen shot taken when hovering the cursor over 'detail design'.

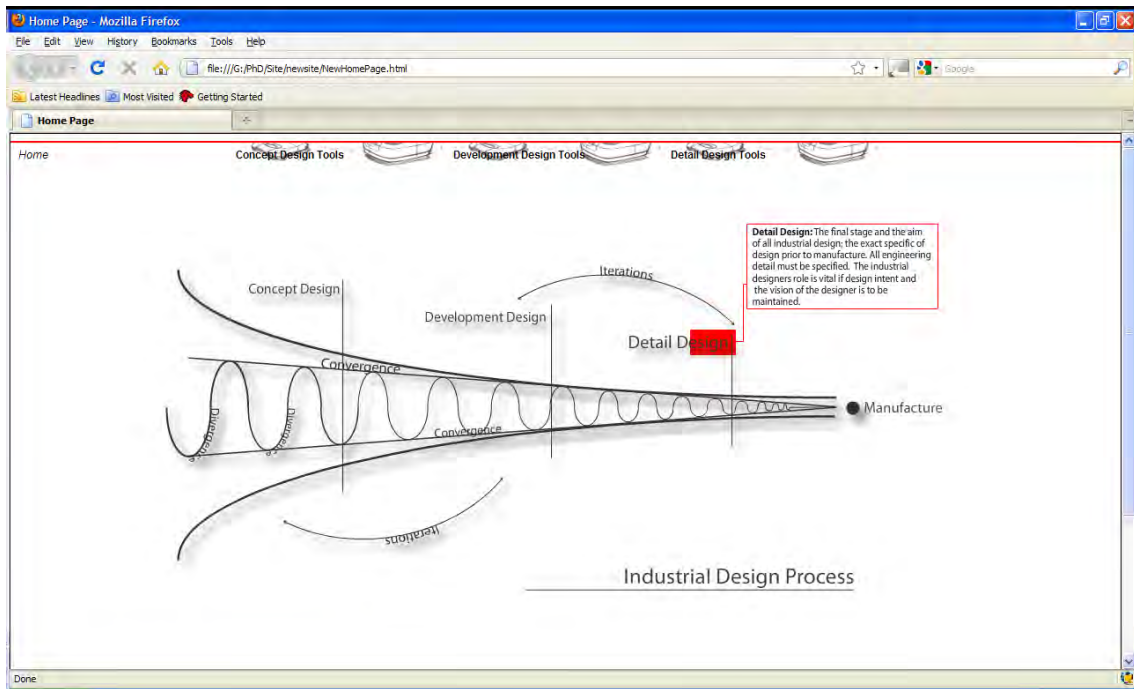


Figure 11 Cursor hovering over detail design to reveal explanation

The site attempted to provide information relating to the nature of the industrial design process. The intention was to suggest how the character of design activity must relate to the various requirements of the design process. A navigation bar, running vertically across the top of the homepage, was used to navigate the various design tools included within the site. Figure 12 illustrates its use:

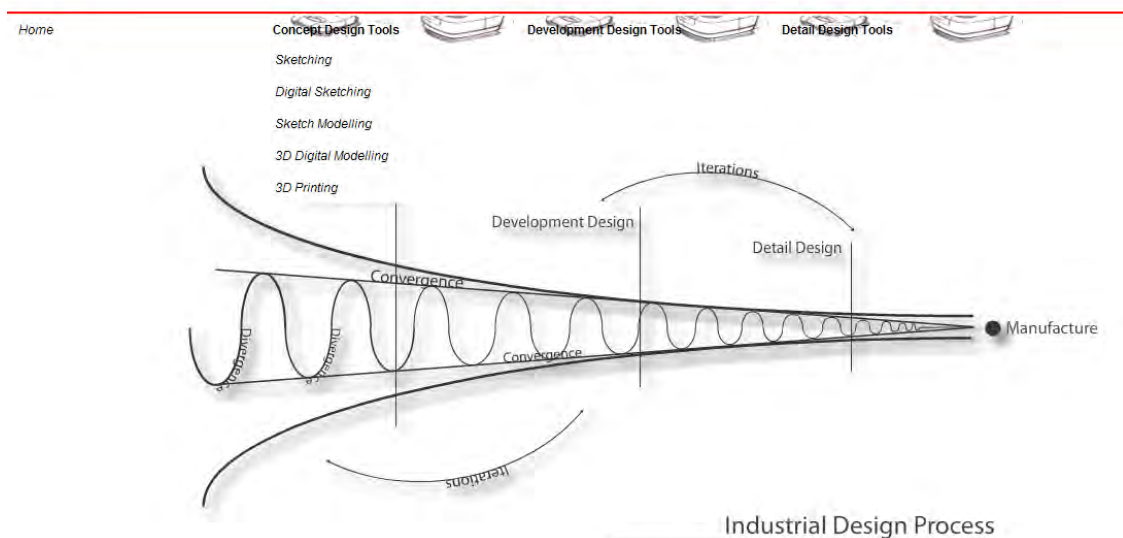


Figure 12 Hovering over 'Concept Design Tools' to navigate site

Hovering over the navigation-bar running along the top of the home page resulted in second level drop-down menus which, when clicked, navigated to a page relating to one of the design tools. Figure 13 illustrates the page for the design tool 3D CAD:

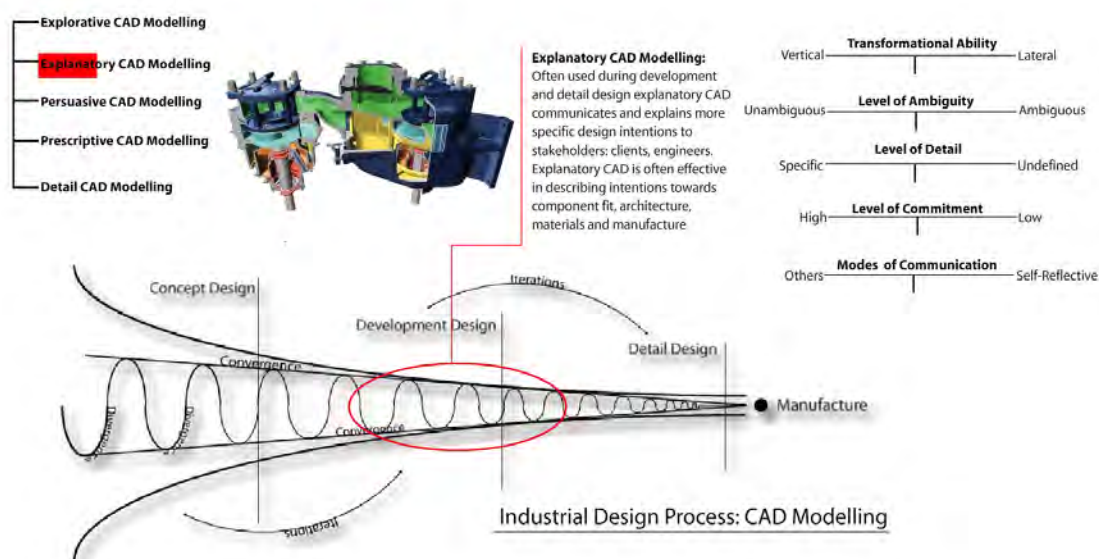


Figure 13 The site's page for the design tool 3D CAD

When entering a page relating to individual design tools the user was presented with the model of the design process together with two smaller navigation bars to the top right and top left (Figures 13). The navigation bar, top right, presented the user with a selection of tool types. In Figure 9.13 there are 5 types of 3D CAD tool presented: explorative CAD, explanatory CAD, persuasive CAD, prescriptive CAD and detail CAD modeling. Hovering over any of these brought up an example image and textual information relating to the tool. In Figure 9.13 above, the cursor hovers over explanatory CAD, displaying information and an example image of the tool. The site also indicated the relationship between tools and their use during the design process. Figure 13 shows where, within the design process, explanatory CAD is most often used to support design activity:

Figure 14 illustrates the page relating to the design tool sketch modelling. In this shot the cursor hovers over the explorative 'Explorative' sketch model type bringing up information relating to this particular type of modelling and indicating where it is often used in the design process to support design activity:

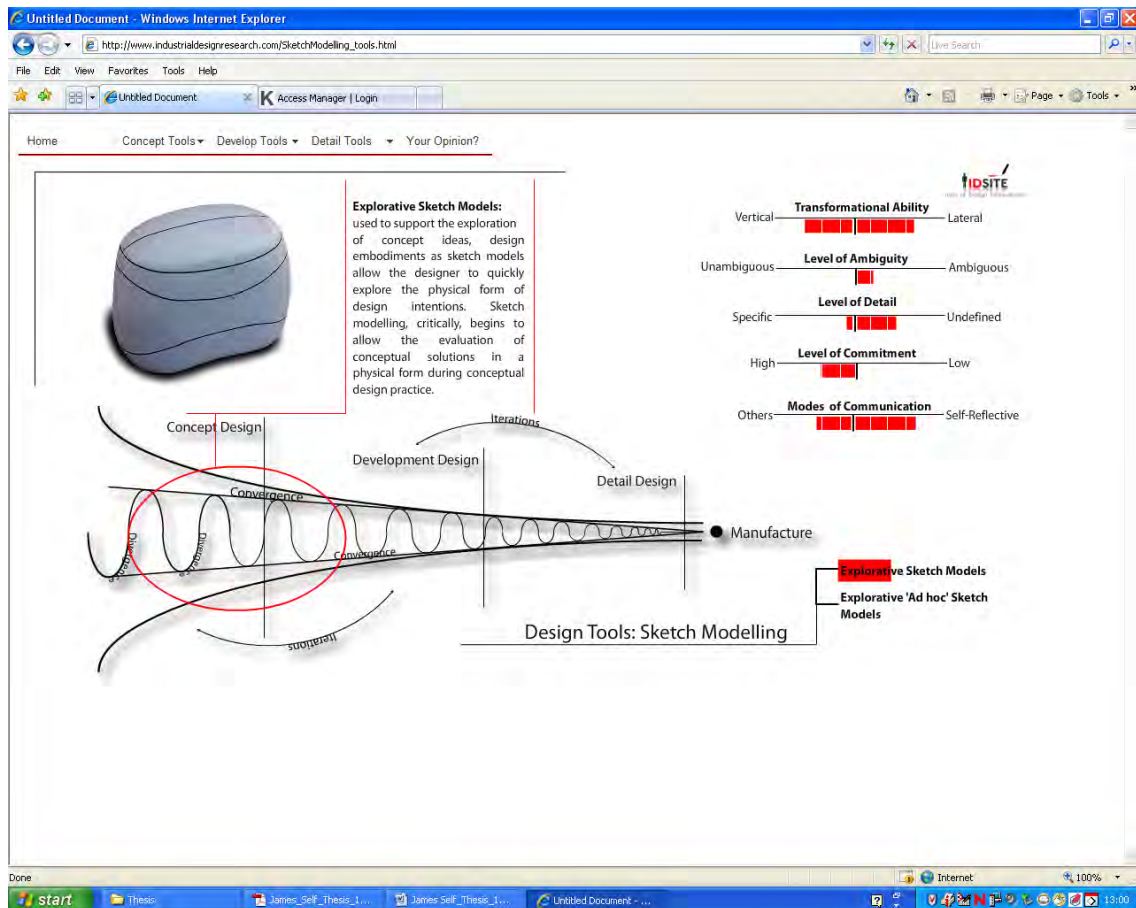


Figure 14 Screen shot showing sketch modelling page

At the top right of each tools page a second menu presents the UTCs presented in Chapter 5. Hovering over these provided information on the five characteristics. Figure 15 shows information relating to graphic illustration. As the cursor hovers over the characteristic 'Level of Commitment', information is displayed relating to the use of the design tool in the embodiment of intent that may communicate more or less commitment:

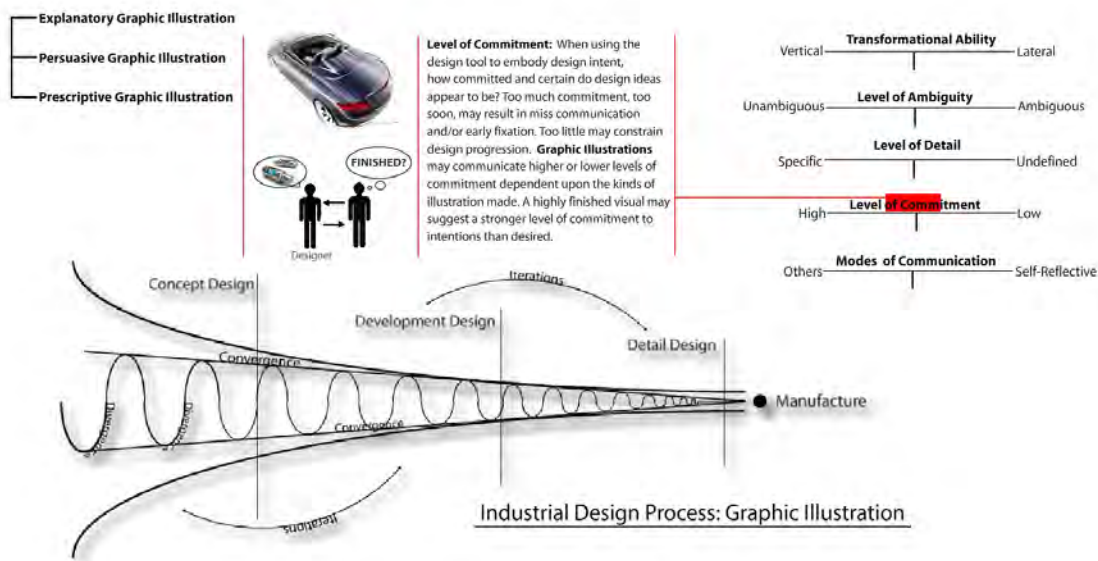


Figure 15 Screen shot showing graphic illustration page and information relating to the characteristic: Level of Commitment

Figure 16 illustrates the design tool sketch modelling. In the screen shot the cursor hovers over the UTC Transformational Ability. Information is then displayed relating to sketch modelling’s ability to support the lateral and/or vertical transformation of design ideas during design activity:

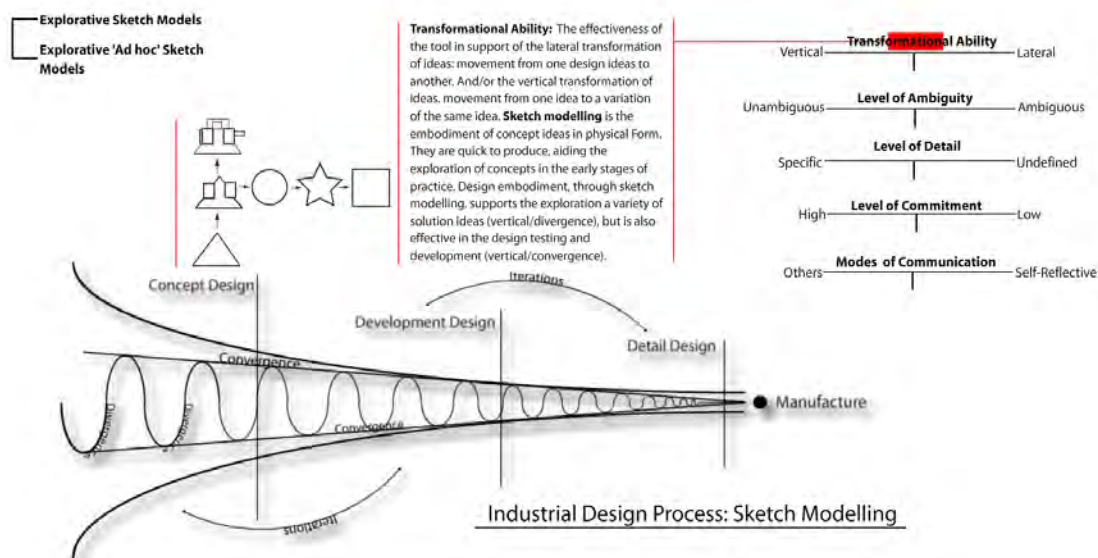


Figure 16 Screen shot showing graphic illustration page and information relating to the characteristic: Transformational Ability

The alpha version of IDsite used research findings to describe the UTCs of design tools. The red bars on each of the 5 UTC scales indicated results from the survey of practitioners (Thesis Chapter 7).

Pilot of IDsite

Before IDsite’s further validation, a pilot study was used to identify initial responses from a target audience of design practitioners and related professionals. The alpha version was sent to a sample of 50 design practitioners. The sample was contacted via email and invited to take part in a survey asking about their opinion of the resource; its ability to support understanding of design tool use during design practice. Attribute questions were first used to gather information on the designers’ employment, education and experience:

- Q1: The practitioners’ place of work
- Q2: Job title
- Q3: The discipline within which the designer worked
- Q4: The length of time worked within the design industry.

A further 6 questions asked of the practitioner’s response to IDsite in its ability to foster understanding of design tools. Rating scales were used to gather data on designer attitudes, with practitioners registering responses using a five item Likert-scale consisting of the following response values: Excellent, Very Good, Average, Below Average and Poor. A final survey question provided the respondents with an opportunity to add comments and suggestions. Of the 50 designers contacted, 16 completed the online survey that represented a response rate of 32%. A copy of the pilot survey can be found in Appendix H.

Pilot Study Results

Figure 17 illustrates results relating to attribute question two, asking respondents about their job title. As the figure suggests, a majority of respondents described themselves as company directors. Together with findings from attribute questions asking about the length of time within industry (Thesis Question 4) findings suggested a majority of respondents had four or more year experience of practice and held senior positions within the companies within which they worked:

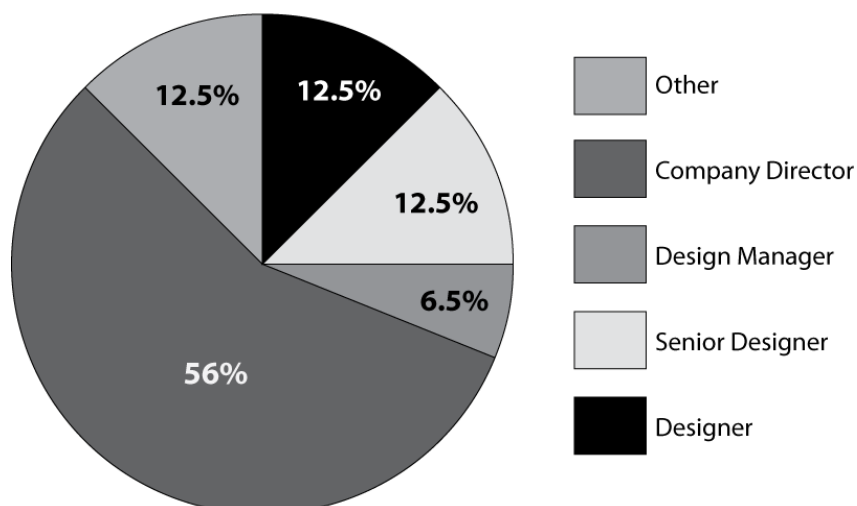


Figure 17 Q2.What is your job title?

Figure 18: Illustrates findings for question 5 which explored the ability of practitioners to navigate the site:

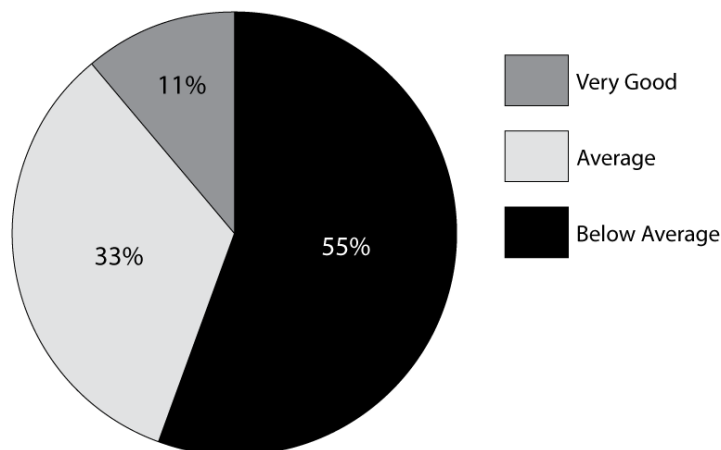


Figure 18 Q5. How do you feel about your ability to navigate the site?

A majority of respondents registered a below average response to this question (black segment), suggesting the designers found the resource difficult to navigate. Problems with the speed and response of the drop-down menus and hover panels were identified as reasons for the designer’s more negative responses. Moreover, some of the qualitative feedback suggested the navigation menu, and the overall presentation of information seemed difficult to understand, ‘The degree of complexity is off-putting.’

Figure 19 illustrates results for Question 6, exploring the capacity of the site to clearly communicate information relating to design tool use during design activity. Although a majority of respondents rated the site as average in its clarity of information (56%), others registered below average (11%) or poor responses (22%). Qualitative responses identified concerns over clarity in terms of the complexity of the resource, ‘In fact I find the general graphics a bit 'unfinished'.

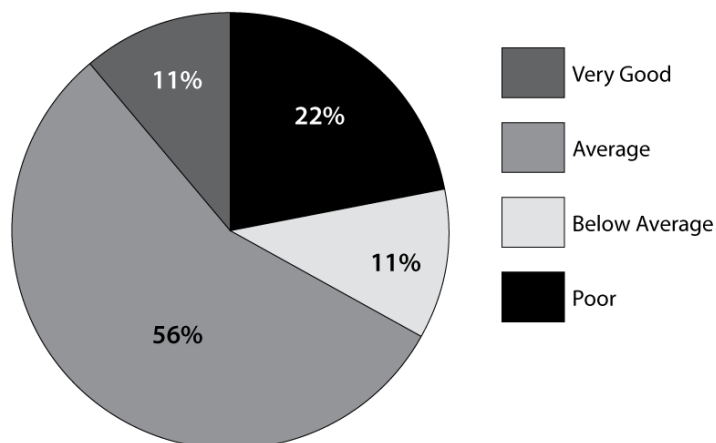


Figure 19 Q6. How would you rate the clarity and understandability of textual and pictorial content?

When asked about the ability of IDsite to describe design practice (Figure 20), 45% registered an average response, with others rating the site as very good (33%) and,

fewer, as below average (22%). Responses suggested designers generally reacted positively to the description of design process. All responses fell within three items of the 5 point Likert scale.

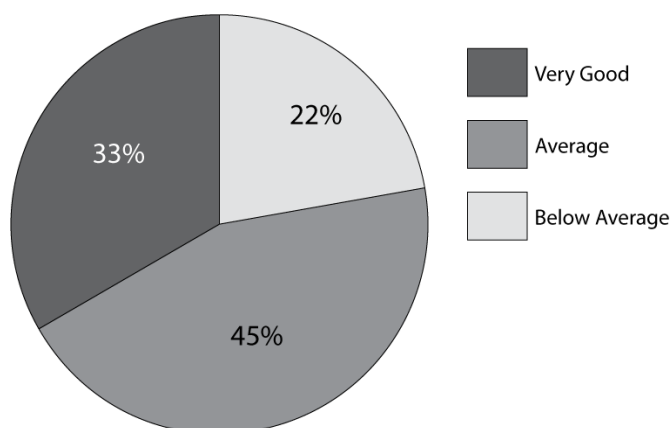


Figure 20 Q7.How would you rate the site's description of the design process?

Figure 21 illustrates results relating to practitioner responses to IDsite's ability to foster understanding of tool use within design activity. A majority of the sample registered an average response (78%), with the remainder indicating a negative attitude towards the site's ability to foster improved understanding. Of the 16 respondents, only half completed question 8, with all responses falling within two of the five items of the Likert scale: poor and average:

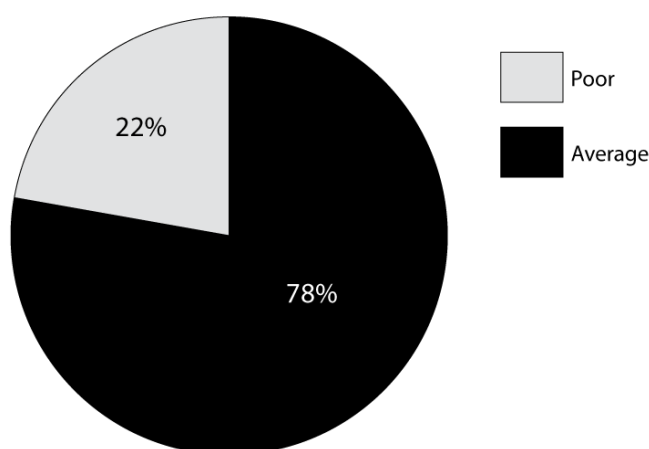


Figure 21 Q8.How would you rate the ability of the site to foster enhanced understanding of various design tools and their support of practice?

Results from the pilot study highlighted problems in terms of the site's ability to communicate research outcomes clearly and effectively. However, as a pilot study, findings were successful in indicating how IDsite might be revised and improved before proceeding with a further round of validation. Encouragingly, although concern was voiced over the design and execution of the site, designers considered the idea of a new approach to research dissemination interesting and relevant, 'A great idea for students, 'It seemed like a good idea but it misses the target in execution'.

Refinement of IDsite

A pilot needed to identify problems to be addressed before further validation of IDsite with a larger sample of designers. Based upon the pilot's findings a number of changes were made to a Beta version of the website. Figure 22 illustrates the revised homepage (see Appendix N for a complete set of plates, illustrating all of IDsite's pages and embedded Flash content).

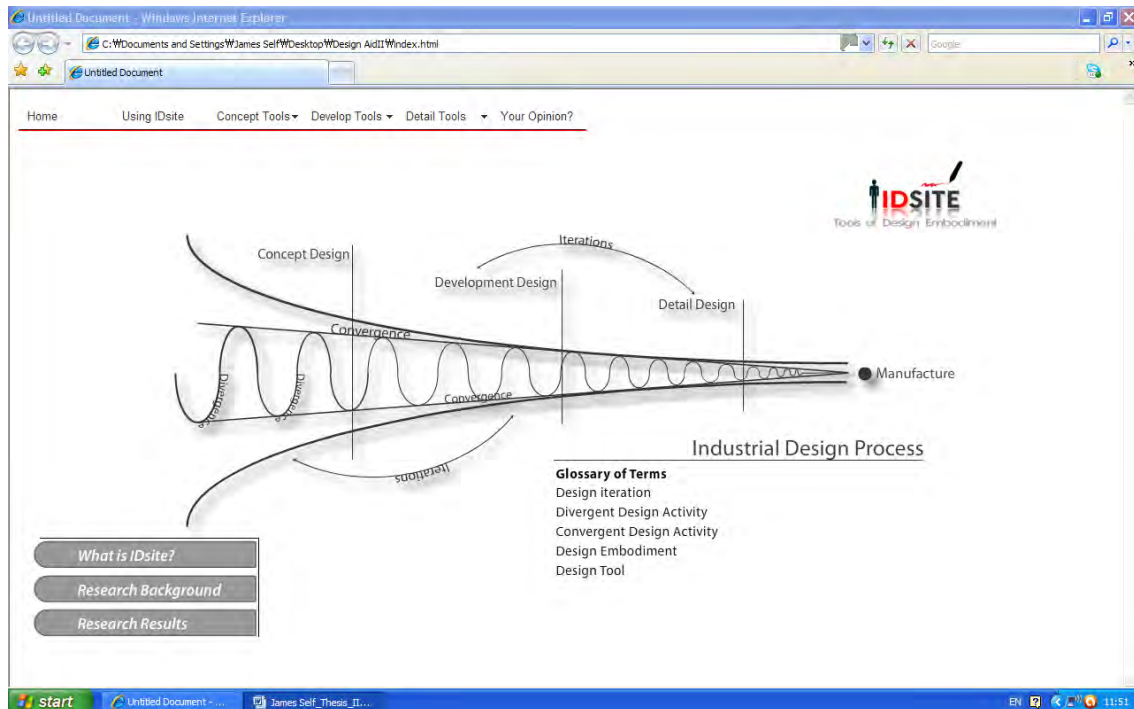


Figure 22 Beta version's home page

It was recognised that the site required a name or brand to help provide visibility and differentiate it from existing design tools. From a discussion with supervisors it was decided the term IDsite would be used and the author proceeded to design and create a logo for use on the site's home page (Figure 23):



Figure 23 IDsite's logo

The logo depicts the sites name along with the strap line, 'Tools of Design Embodiment'. The representation of a figure is a reference to the individual designer and their influence upon tool use. The pencil is used as indication of the website's area of concern, tools of design embodiment.

The pilot study resulted in a favourable response to the site’s model of design process. As a result no change was made to the model presented in the alpha version of the site. In response to the pilot results, suggesting concern over the ability of users to navigate IDsite (pilot study, question 5, see Appendix H) the navigation bar, running vertically along the top of the screen, was revised. To add clarity a white bar with a red bottom border was used as background to all items including drop-down panels, which appeared when hovering over the items in the menu (Figure 24). As the cursor hovers over items they then turn grey, contrasting with the site’s white background colour.

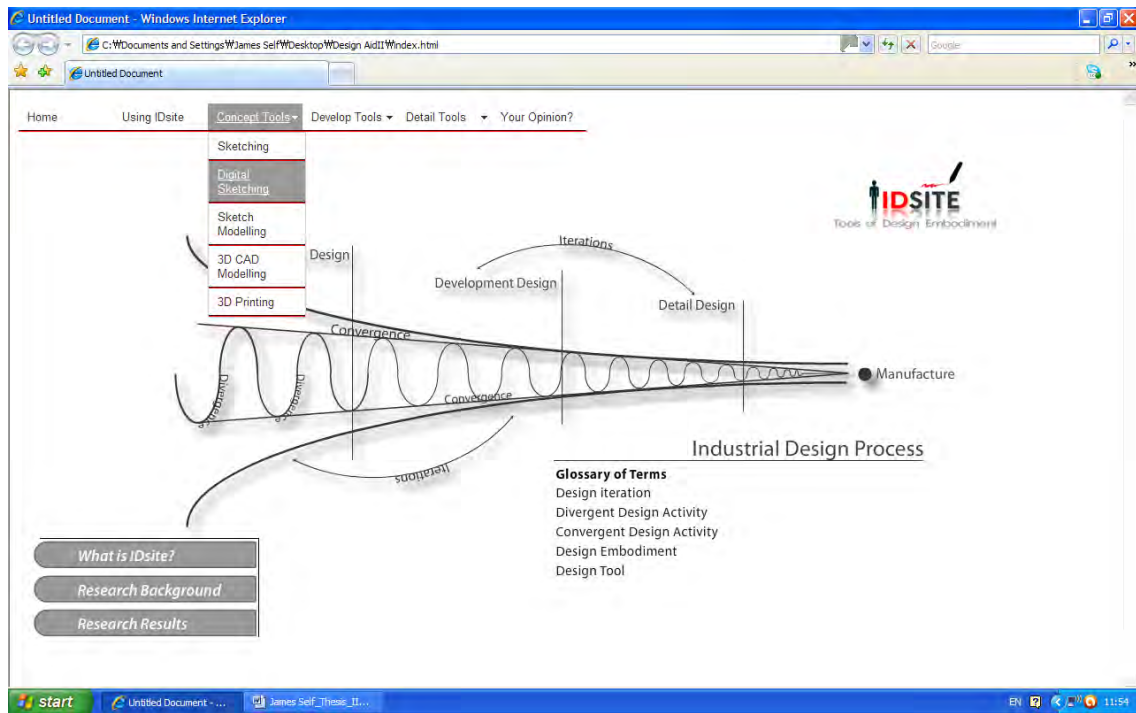


Figure 24 Use of the navigation bar to navigate between tools pages

A summary of the aims, methods and results of the doctoral study were also added to the homepage. Hovering over ‘What is IDsite?’ provides information relating to the site’s aims in communicating knowledge of design tools (Figure 25):

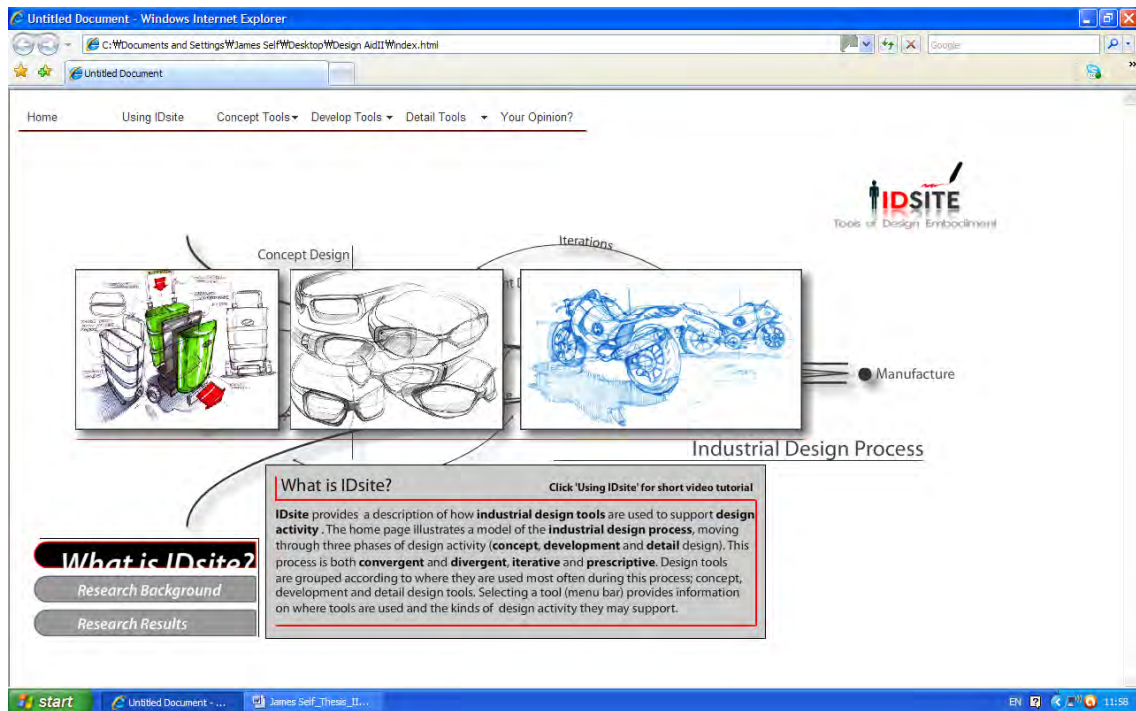


Figure 25 Screen shot (home page) showing information relating to aims of IDsite

Hovering over 'Research Background' outlines the role of the site in relation to the doctoral study (Figure 26):

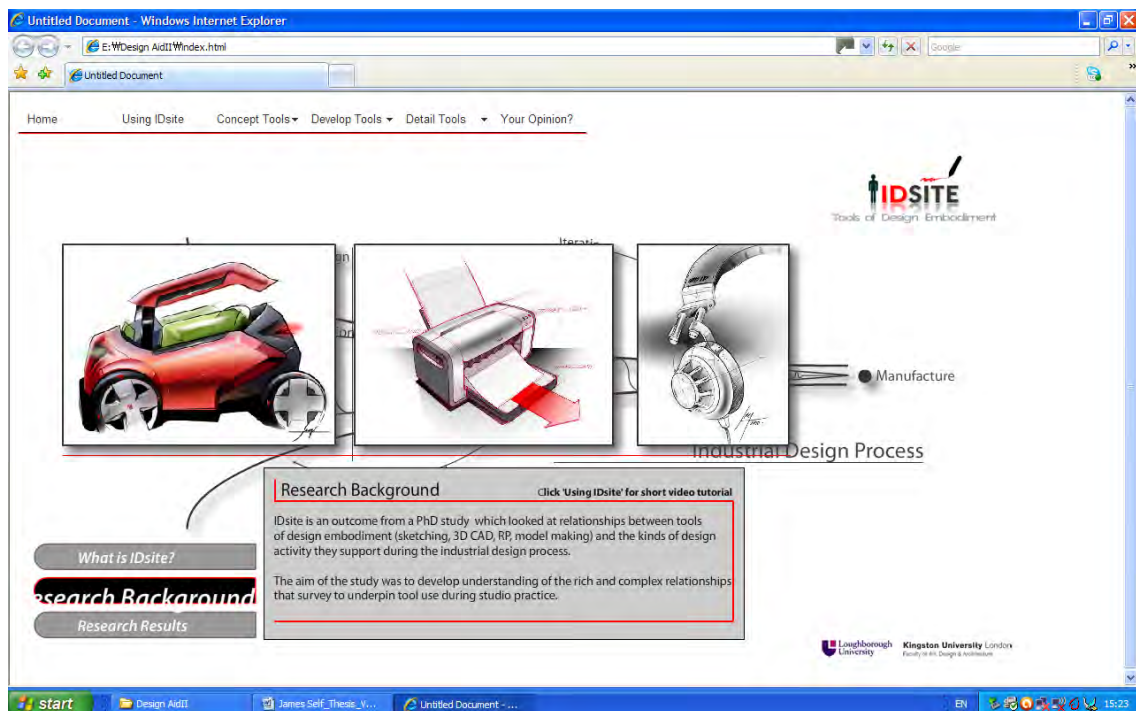


Figure 26 Screen showing background to Research

Hovering over 'Research Results' provided information relating to the outcomes of the study and how they informed IDsite's design (Figure 27):

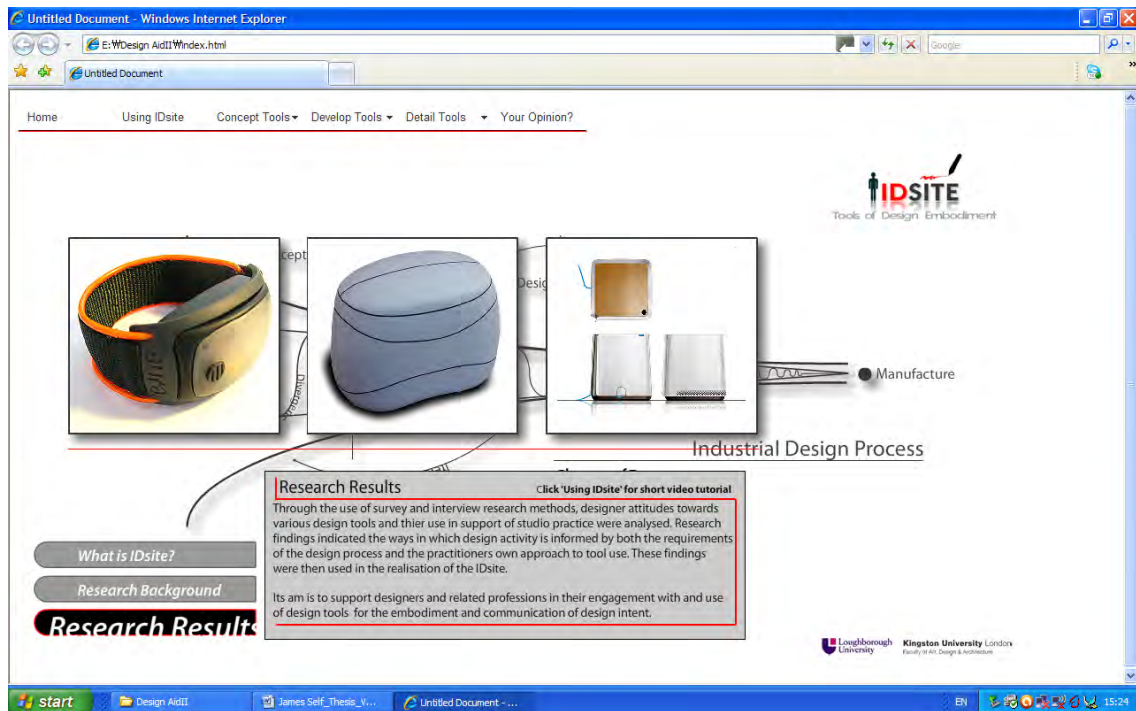


Figure 27 Screen shot showing information relating to research results

A glossary was added to explain key terms used in the discussion of design tools and their role in support of design activity (Figure 28). This responded to pilot findings suggesting concern for the complexity of information presented and the user’s ability to make sense of the terms used within the site:

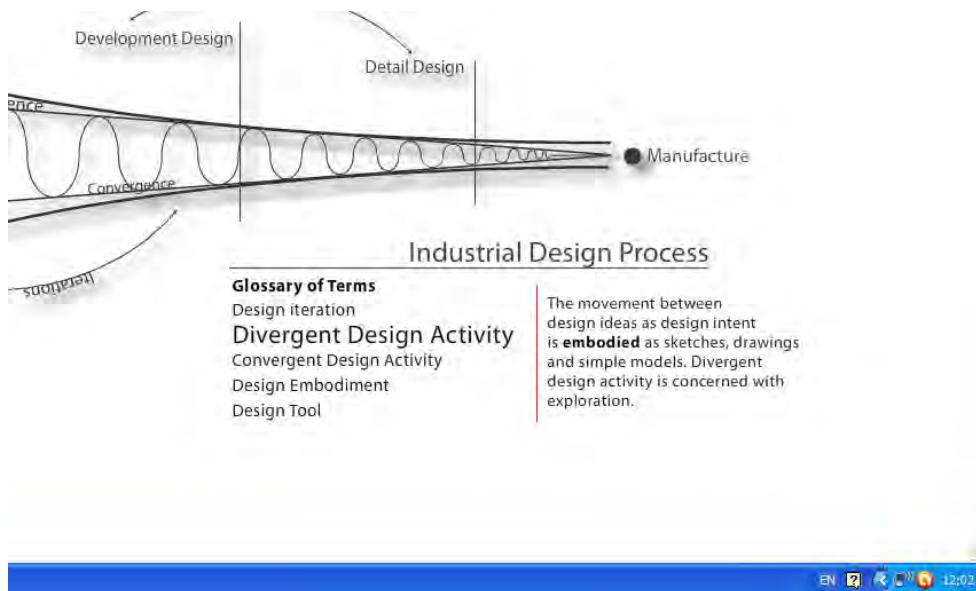


Figure 28: Screen shot showing use of glossary of key terms

The model of the design process had a number of interactive hot-zones that, when hovered over, provided information relating to stage in process and the nature of the design process. Figure 29 illustrates the presentation of information as the cursor hovers over concept design (for a full set of IDsite plates, see Appendix N):

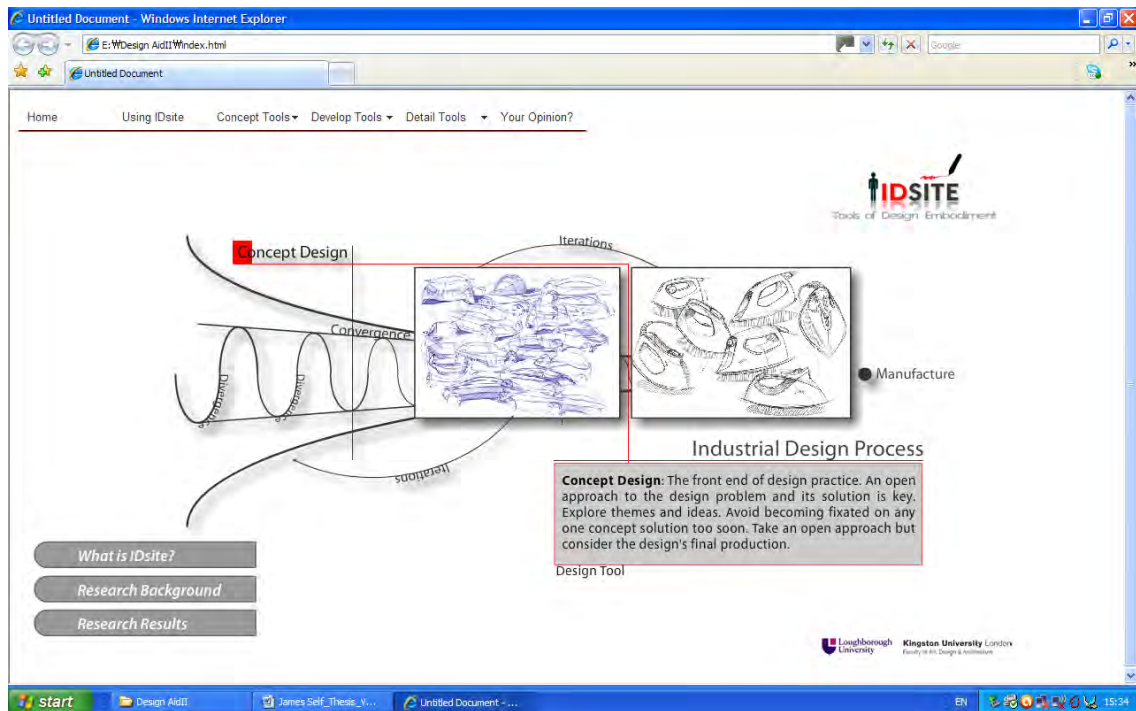


Figure 29 Presentation of information as cursor hovers over concept design

In response to concern over complexity and navigational ability, a short video tutorial was embedded within the site. The tutorial provided an example of how IDsite might be navigated and the role of the various menus and media within it. Figure 30 illustrates the opening screen to the video tutorial:

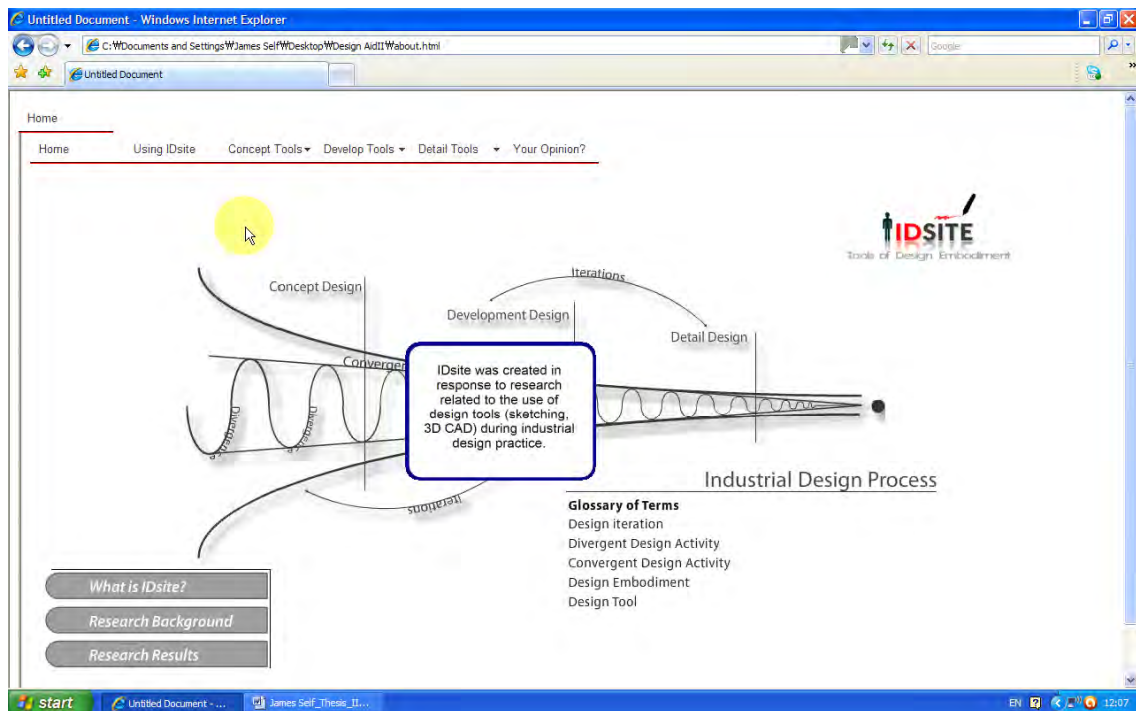


Figure 30 Opening sequence to tutorial

At the start of the tutorial a screen annotation was used to briefly describe research aims. Following this, further screen annotations provided explanations of how to navigate the model of design process. Figure 31 shows the tutorial as it presents navigation of the model of design process:

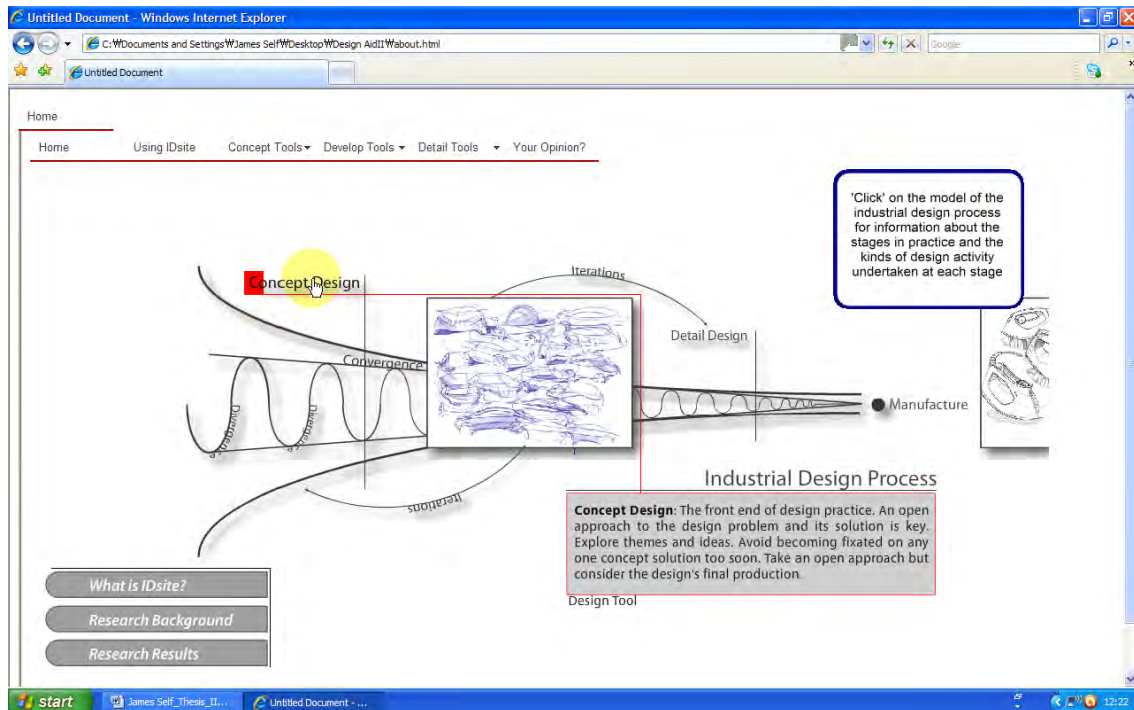


Figure 31: Screen annotation describing how to navigate the model of design process

The tutorial described site navigation and explained how to use the white/red navigation bars (Figure 32):

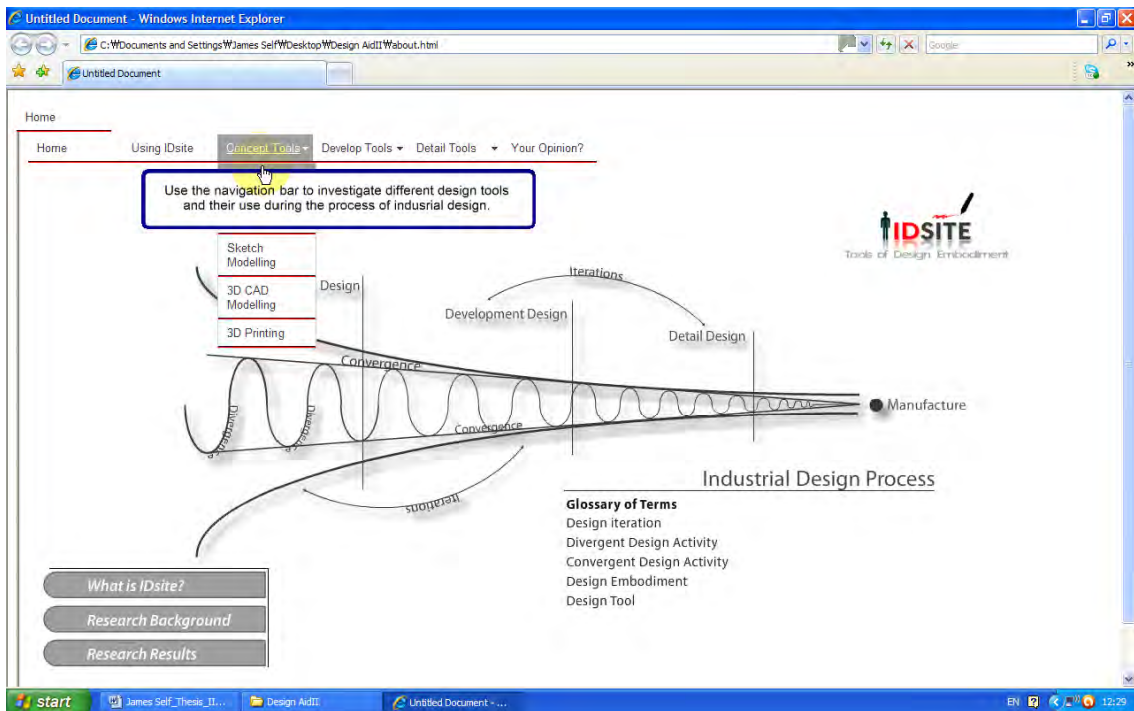


Figure 32: Screen annotation describing how to navigate the site

Finally, the tutorial presents an example page relating to an individual design tool as it appears in the site (Figure 33, hand sketching):

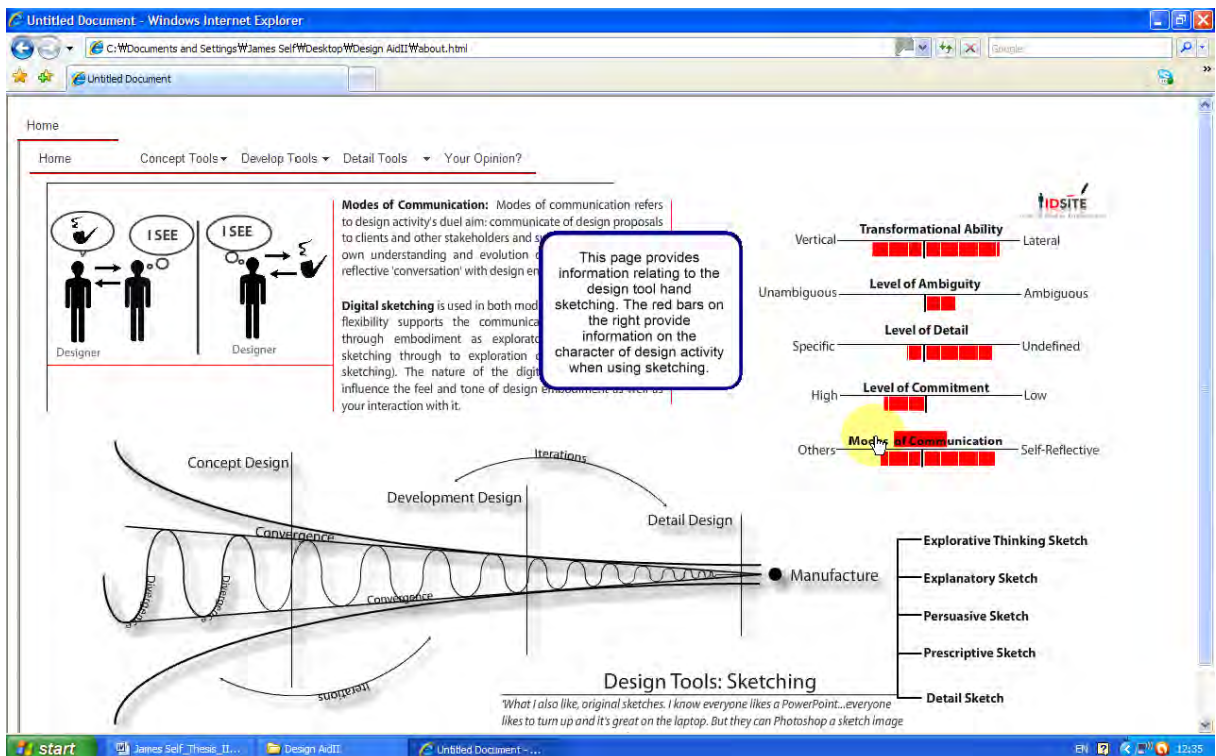


Figure 33 Screen shot from video presentation of design tool hand sketching

The presentation proceeded to describe the features of the page relating to hand sketching tools. This included an explanation of the use of the navigation bar relating to the characteristics of design activity and navigation of the bar relating to the kinds of hand sketching often used to support design activity (Explorative thinking sketch, explanatory sketch, persuasive sketch, prescriptive sketch, detail sketch, Figure 33). In this way the video tutorial aimed to support understanding of the site's key features and provide an explanation of how they may be navigated. This sought to address designer concerns identified in findings from the pilot study (complexity and navigation).

An alteration was made to the layout and presentation of information on each of IDsite's tools pages. Figure 34 illustrates the Beta version's page layout for the design tool Sketching.

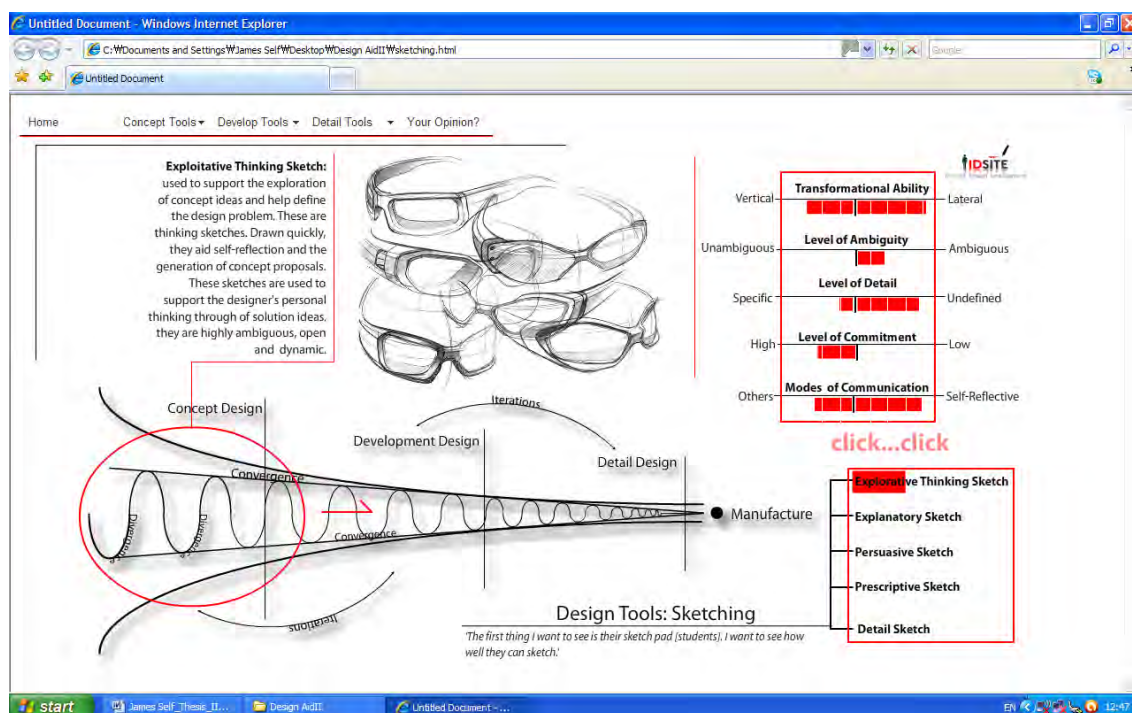


Figure 34 Layout of Beta versions design tool page: Sketching

In response to the pilot's findings indicating user concern over navigation and presentation of information the menu bar, relating to the kinds of embodiments made when using individual tools was moved from the top left to the bottom right of the screen (Figure 34). This then grouped both interactive menus to the right of the screen. A prompt to 'click' on these menus was also given (Figure 34, 'click...click'). Hovering over items within these two menus provided information relating to the characteristics of design activity when using a given tool (top menu), the kinds of design tools used to support activity and how their use related to the design process (bottom menu).

Figure 35 is a screen shot taken from the page in IDsite's that relates to the design tool rapid prototyping. The cursor hovers over the menu item, 'prescriptive RP'. This then provides information relating to design embodiment as 'prescriptive rapid prototyping'

together with an example graphic. Prescriptive rapid prototyping's use within the design process is also indicated (red oval over model of design process, Figure 35):

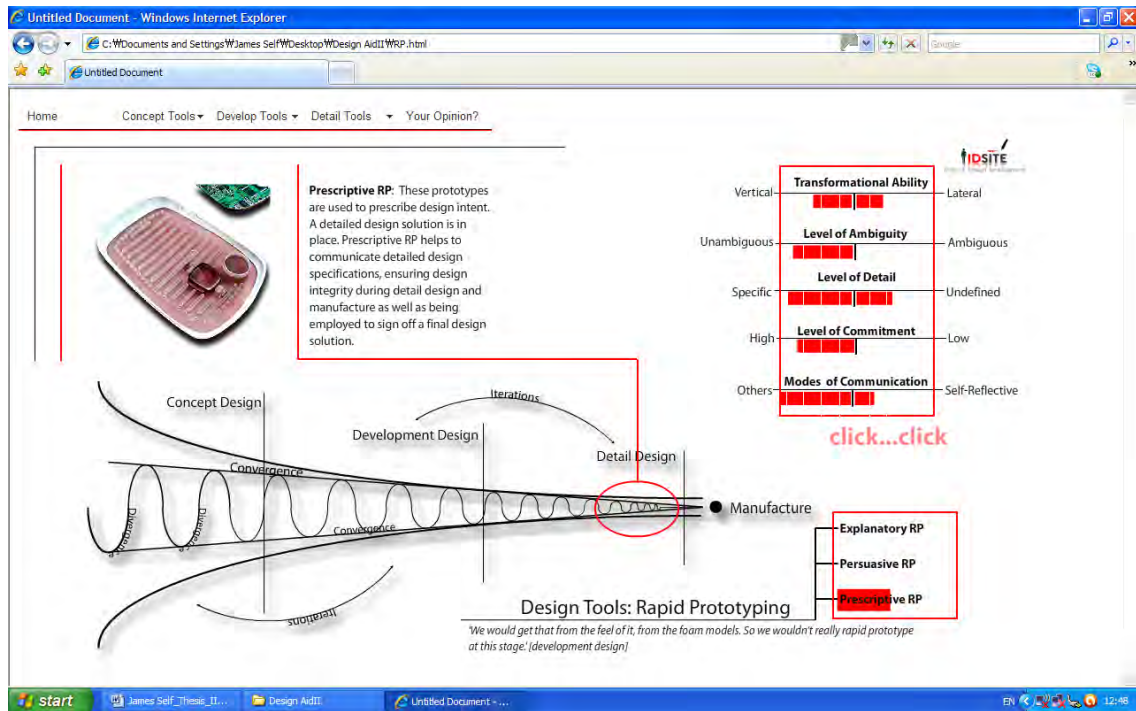


Figure 35 Cursor over prescriptive RP

Figure 36 illustrates the page relating to the design tool hand sketching. The cursor hovers over the characteristic 'Level of Commitment' (sub-menu to the screen's top-right). Graphic illustration accompanies text describes the degree to which the use of sketching may communicate commitment to design intent.

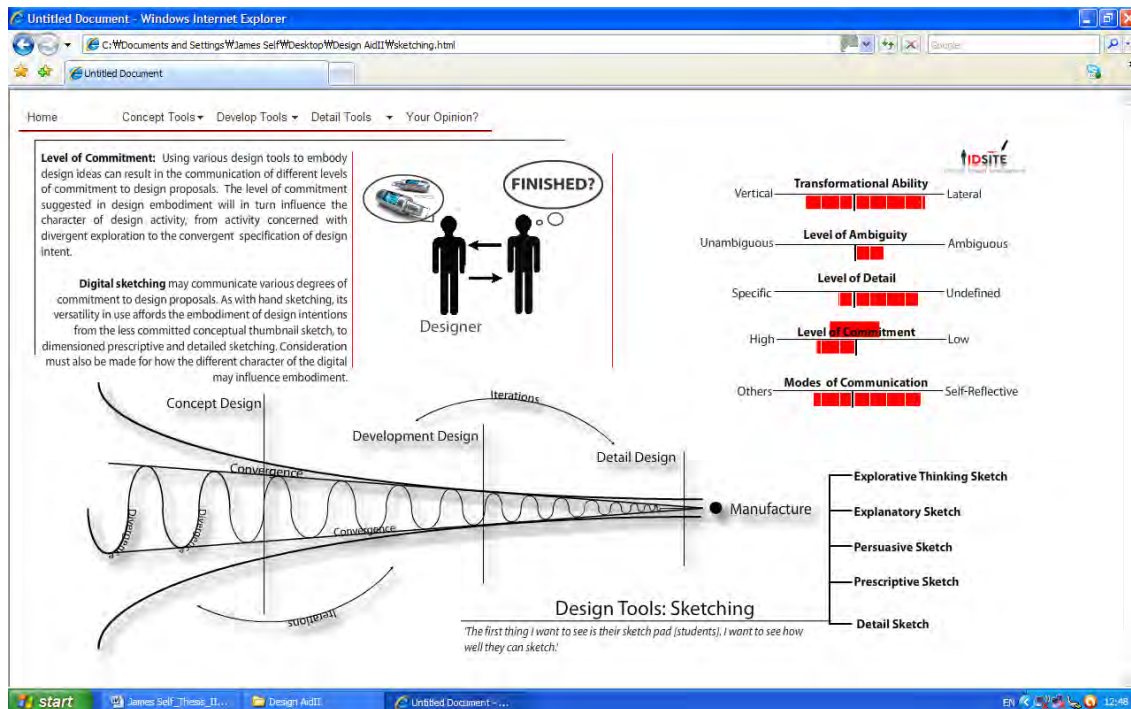


Figure 36 Cursor hovers over Level of Commitment

These changes concluded the response to concerns identified in the pilot study. The following section describes IDsite’s further validation through a larger study with samples of designers and design students (for IDsite’s complete set of plates see Appendix N).

Appraisal Framework, Strategy & Reliability of Results

The aim of IDsite’s validation was to obtain feedback from designers on its ability to support their understanding of and engagement with design tools during studio practice. Validation was by way of a two-phase strategy. A first phase involved the survey of a sample of 91 design practitioners and related professionals. The purpose was to gather data relating to attitudes towards the ability of IDsite to communicate understanding of the use of design tools. A second phase consisted of a focus group of 20 undergraduate industrial and product design students at Kingston University, London.

The design directories available through the industrial design blog, Core77 (2010) and the Directory of Design Consultants (2009) were again used to source designer contact details. Letters of invitation (Appendix I) were sent inviting designers to test and critique the site through an online survey (Appendix J). The student focus group was also provided with an identical paper survey (Appendix K). The two phases of validation covered a period of four weeks.

Results from the pilot study were used to inform the final survey questions. The student focus group was also given a short overview of the study, its aims and objectives. However, the researcher was careful not to prescribe the ways IDsite might be used. The intention was to allow both samples to navigated and explored the site in the same

way as the intended audience might when using IDsite online, rather than providing a set of instructions or recommendations on how to use the site.

In terms of the online survey, closed questions were used to gather information on respondent attributes, followed by a set of five-item Likert-scale questions and a final open-ended question. Responses to each of the items on the Likert-scale and attribute questions were then calculated as percentages. The final open question provided an opportunity for practitioners to provide qualitative feedback on the future development of the site. The survey conducted with the student focus group was identical to the one used to survey design practitioners with the exception of the omission of the attribute questions. This was considered unnecessary as the researcher was aware of the students' level of experience.

The practitioner respondents were made aware of the nature of the survey and how the data they provided would be used (Appendix J). They were also told the study complied with Kingston University's ethical guidelines and that their identities and the identity of the organisations for which they worked would be kept in confidence. In the same way focus group participants were made aware of their role in the study, that responses would be anonymous, personal data would not be collected and that they were free to leave at any time.

Reliability of findings was achieved through a methodical approach to data collection, a substantive sample size (91 practitioners, 20 student designers), and the use of a pilot study prior to validation to inform IDsite's design and the questions asked through the online survey and during the focus group.

Data Collection of Online Survey

A first stage of validation involved a survey study of design practitioners over two weeks. Four initial questions were used to gather data on the respondents' attributes (Table 1):

4 Questions Designed to Gather Data on Practitioner Attributes
Q1: How would you describe the consultancy/organisation for which you work?
Q2: What is your employment/position in your organisation?
Q3: How would you describe the design discipline in which you work? (check all that apply)
Q4: For how long have you worked in the above profession?

Table 1 List of survey attribute questions

Following these four attribute questions, a further four questions were asked to gather feedback on the respondents attitudes to IDsite. Three of the four questions used five-item Likert-scales as a means to gather data relating to the designers' opinion of the site. A further question asked respondents to suggest possible audiences for the site (Table 2):

4 Questions to Gather Data on Practitioner Attitudes	Response Items on Scales
--	--------------------------

Q5: Looking at IDsite’s homepage, how accurate is the model of the design process?	Very Accurate	Somewhat Accurate	Not Sure	Not very Accurate	Not Accurate at All
Q6: Do you find the images and text effective in helping to describe design tools and their relationship to the design process?	Very Effective	Somewhat Effective	Not Sure	Not very Effective	Not Effective At All
Q7: Would the site help any of the following groups better understanding the role design tools play in support of the design process? (check all that apply)	Undergraduate Students				
	Novice Designers				
	Postgraduate Students				
	Design Educators				
	Design Researchers				
	Mid-weight designers				
	Experienced designers				
Q8: Would IDsite help you to better understanding relationships between the design tools you use and their support of the various requirement of the design process?	Defiantly Will	May Do	Not sure	Will Not	Defiantly will Not

Table 2 List of survey attitude questions indicating items on response scales

A final open-ended question provided an opportunity for respondents to provide qualitative feedback:

Q9: Finally, please use this space to provide any further observations or suggestions to help us improve IDsite.

A contact email also provided respondents the opportunity to receive a report of results:

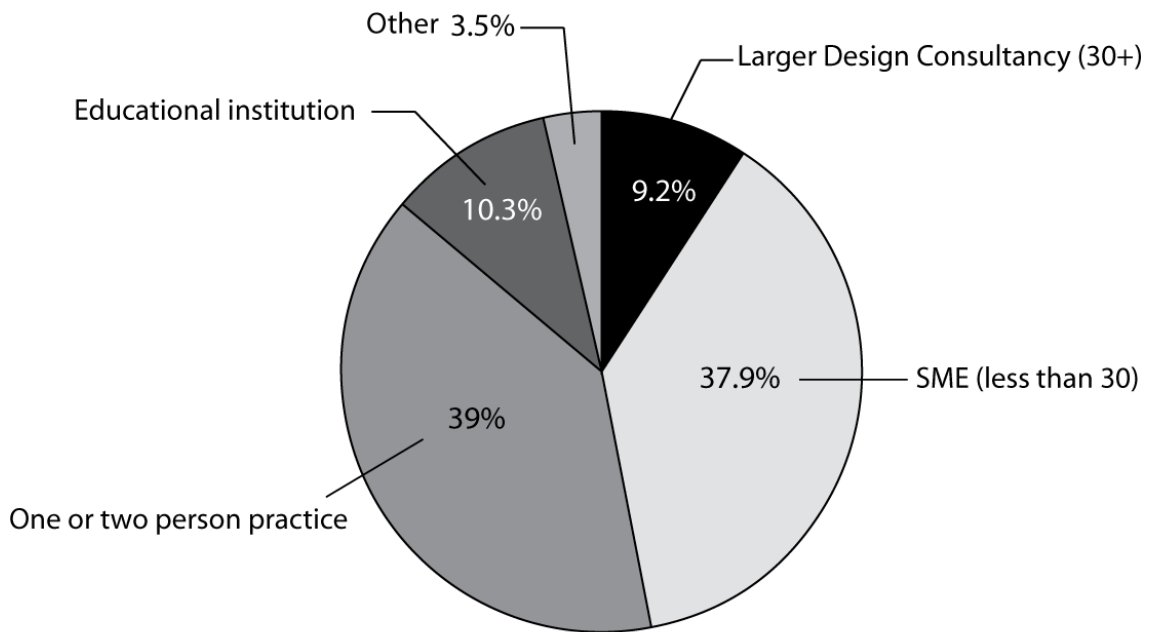
- Would like to be sent a summary of the results? If so, please enter your email address below.

Survey Findings

As with earlier studies of designer attitudes towards design tools (Thesis Chapters 7 and 8) an online survey was used to gather designer data on designer attitudes towards IDsite. The online survey provided a results database; presenting data as a total number of responses to items in each of the survey questions and as a percentage of the total response to each question (Appendix L). This data is used in the graphic representation of survey findings through pie-charts and bar-charts below.

Four survey questions gathered data on respondent attributes (Table 1). A first question asked respondents about the nature and size of the organisation for which they worked. 39% or 34 designers identified themselves as working within a one or two

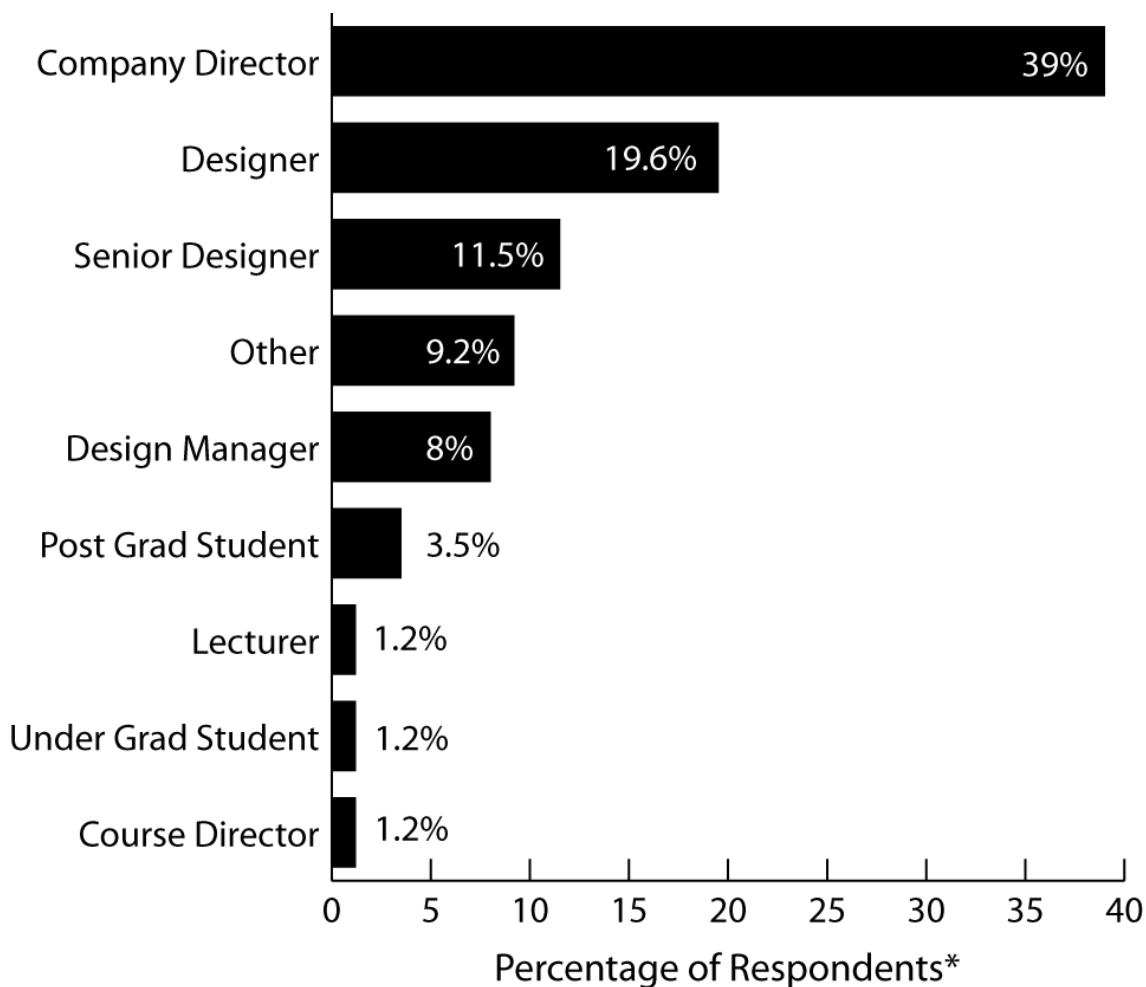
person design practice. 37.9% described themselves as working within a Small to medium size enterprise (Figure 37):



*87 Responded and 4 skipped this question

Figure 37 Q1: How would you describe the consultancy/organisation for which you work?

Results indicated the majority of respondents worked within smaller consultancies, partnerships or as individual and fee-lance designers. A second question asked the respondents about their job title and position within the company they worked (Figure 38):



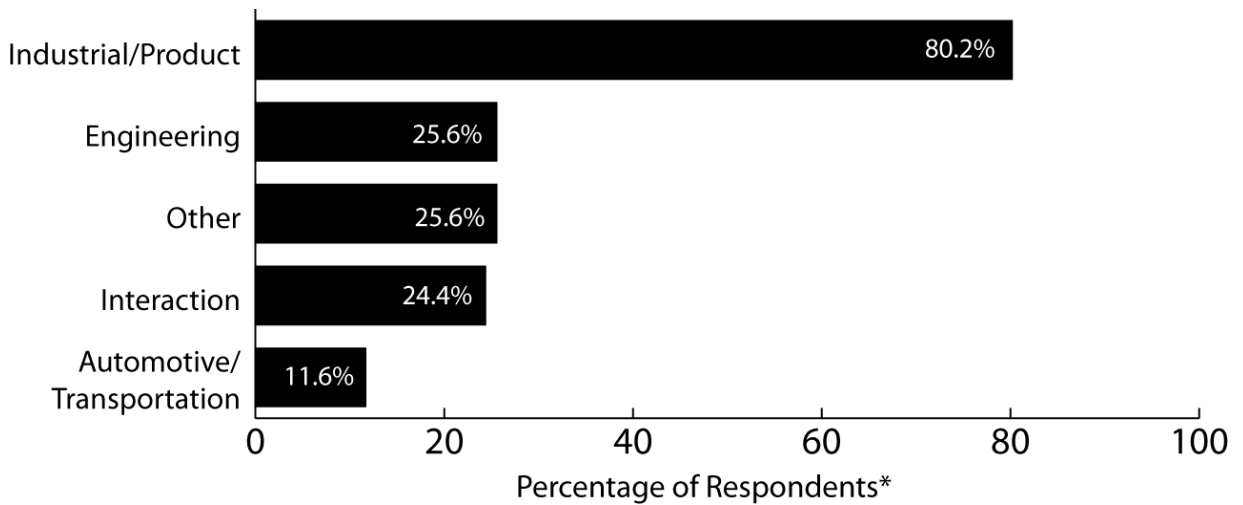
*87 Responded and 4 skipped this question

Figure 38 Q2: What is your employment/position in your organisation?

39% (34) of the respondents identified themselves as company directors. This was almost twice as many as the next greatest category (Designer 19.6% or 17 respondents). 9.2% or 8 respondents recorded 'Other' as their employment position, with 8% (7) described themselves as design managers, 5 (5.75%) as design researchers. The remaining respondents identified themselves as post graduate students (3.5%, 3) and lecturers, undergraduate students and course directors (1.2% or 1 response for each). Findings suggested a majority of respondents were in senior positions within the organisations within which they worked. Findings from question 4, asked about the respondents' experience of practice and indicated higher levels of expertise (see Question 4, below).

A third attribute question asked respondents to describe the discipline within which they worked (Figure 39). For this question respondents were prompted to indicate all disciplines that applied. A majority of respondents described themselves as industrial/product designers (80.2%, 69 respondents). Approximately a quarter recorded responses of engineering design, interaction design and other (25.6% or 22,

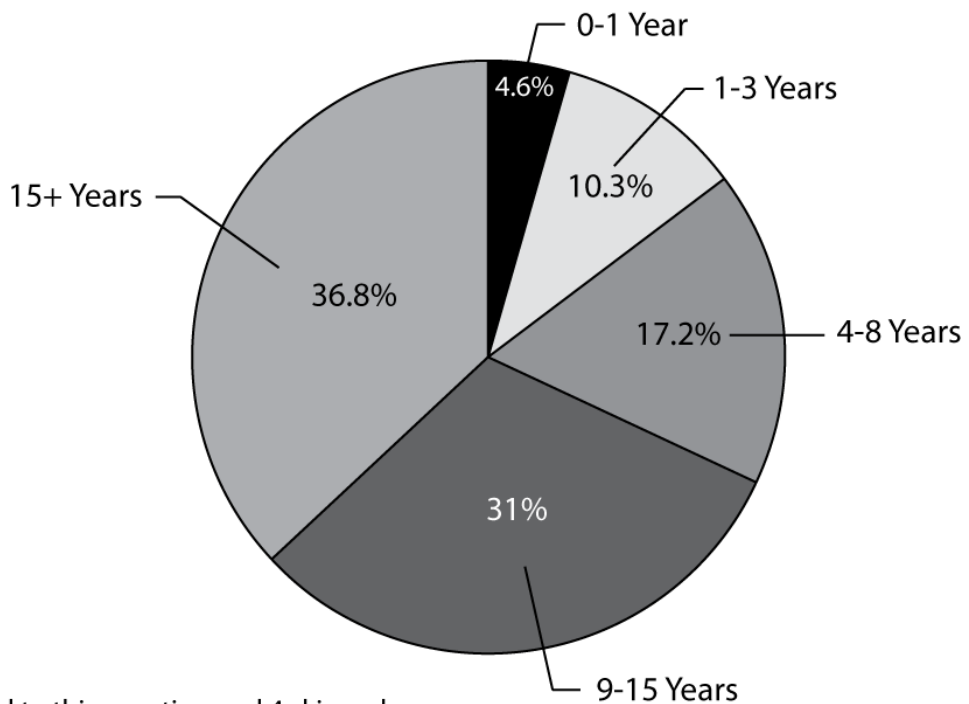
24.4% or 21 and 25.6% or 22 respondents). 11.6% or 10 described themselves as working within the automotive and transportation sector:



*86 Responded to this question and 5 skipped.

Figure 39 Q3 How would you describe the design discipline in which you work? (Check all that apply)

Attribute question 4 asked respondents about the number of years experience they had within the discipline(s) indicated in question 3 (Figure 40):



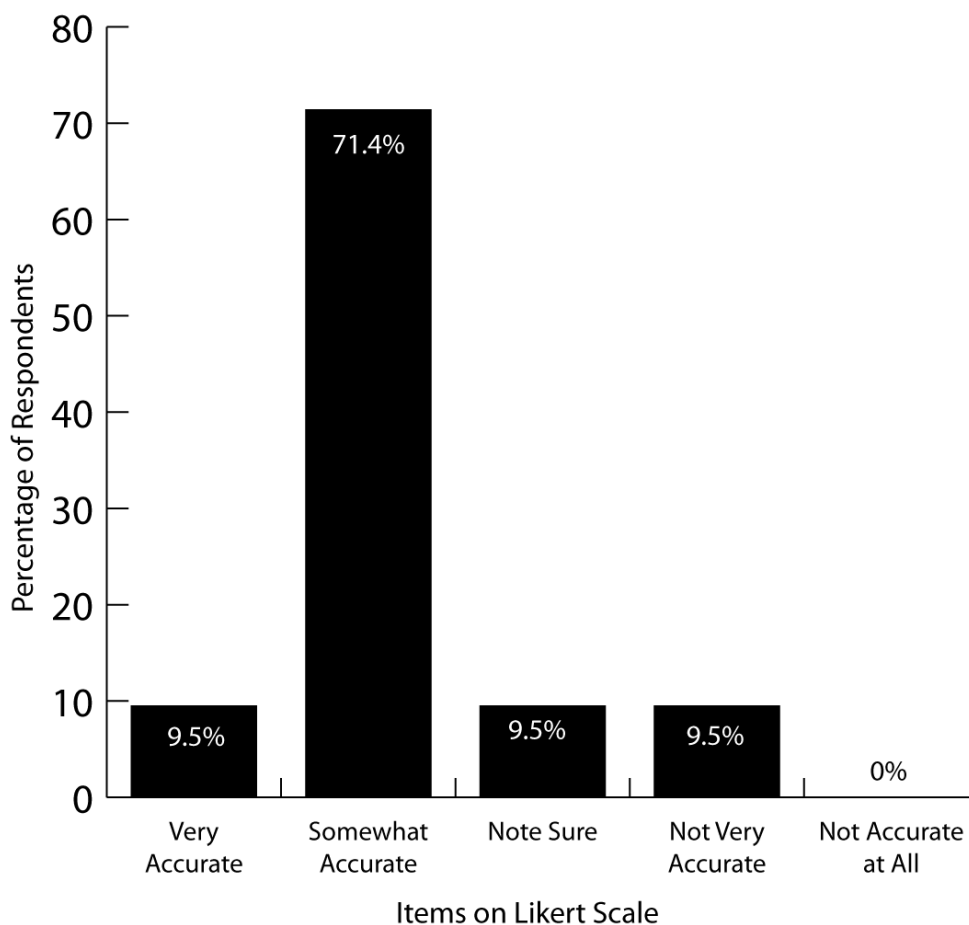
*87 Responded to this question and 4 skipped

Figure 40: Q4 For how long have you worked in the above profession?

Agreeing with responses to question 2 (asking about respondent job titles) 36.8% or 32 respondents described themselves as having 15+ years of experience in practice. This

percentage reduced through the lower categories of experience presented in the survey. 31% or 27 respondents describing themselves as possessing 9-15 years experience, 17.2% or 15 as having 4-8 years, 10.3% or 9 as possessing 1-3 years experience and 4.6% or 4 with only 0-1 years experience. Based on these results a majority of respondents had considerable experience of practice and may be described using the Dreyfus & Dreyfus (Dreyfus 1986) model of expertise as ‘expert’ within the disciplines for which they work. Moreover, the sample came from the intended audience or user group for IDsite and most worked within medium or smaller sized consultancies.

Survey question 5 asked respondents of their reaction to the model of the design process presented on IDsite’s homepage (Figure 41):



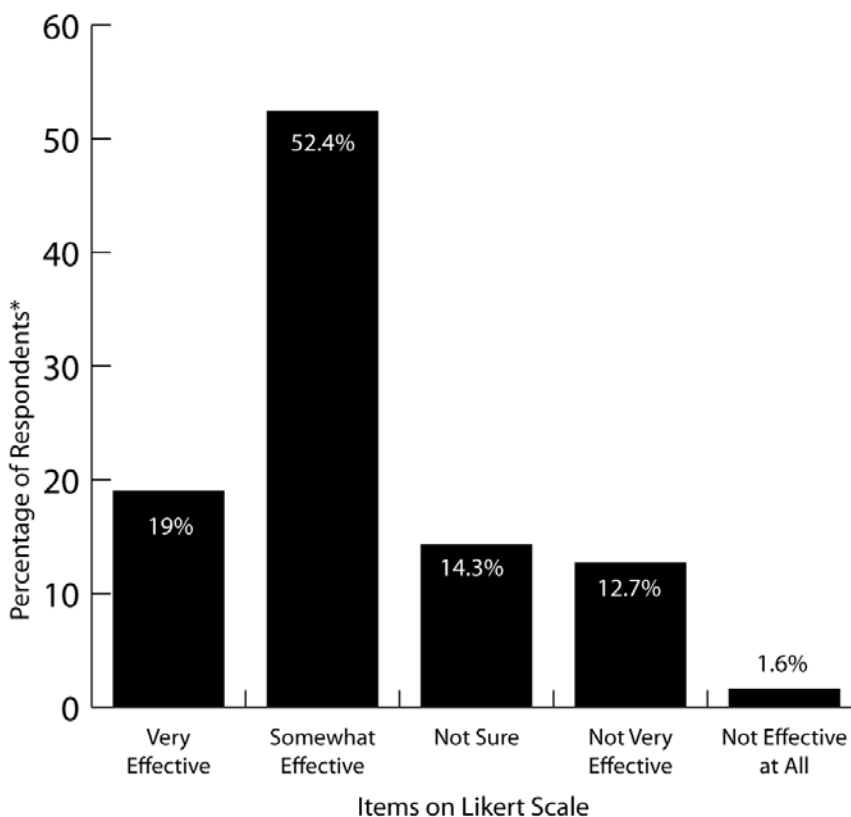
*63 Responded and 28 skipped this question

Figure 41 Q5: Looking at IDsite’s homepage, how accurate is the model of design process?

A majority of respondents registered a response of ‘Somewhat Accurate’ (71.4%, 45 respondents). 9.5% or 6 registered a response of very accurate, not sure and not very accurate. The results indicated a majority of the sample considered the model of the design process to be reasonably accurate in describing studio practice. Individual responses at question 8 (asking for further observations or suggestions to help us improve IDsite) indicated some designers considered the lack of a briefing phase,

indicated in the model prior to concept design to be of concern. Another respondent described a need to include design research prior to commencement of conceptual design. Another suggested the model needed to include the relationship between client and user needs and the ways in which this may influence the design process and studio practice, ‘Core methodological practices such as user research, human factors, opportunity mapping, prototyping, usability testing are missing’ (respondent 62, Appendix M). Generally, however, results suggested a majority of respondents reacted positively to the three stage, divergent/convergent model of the design process presented on the site’s home page.

Question 6 asked of IDsite’s effectiveness in describing how design tools relate to the design process, as presented in the model (Figure 42):



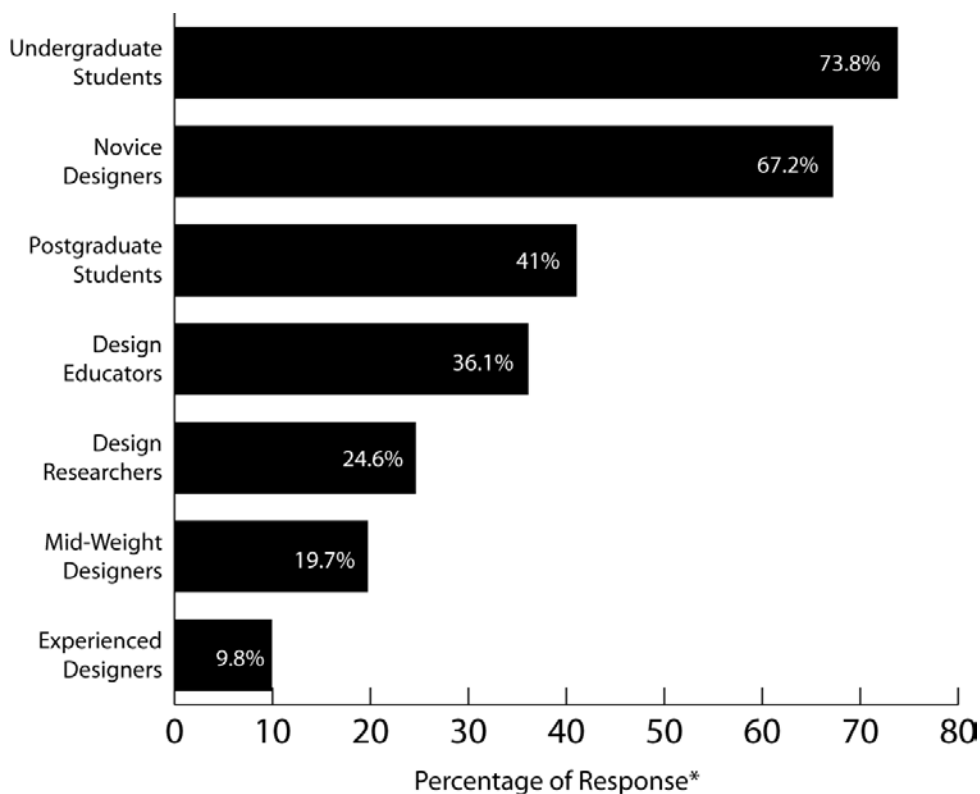
*63 Responded and 28 skipped this question

Figure 42 Q6 Do you find the images and text effective in helping to describe design tools and their relationship to the design process?

As with question 5, a majority of respondents recorded a response of ‘somewhat effective’ when asked of the site’s effectiveness in describing relationships between tool and process (52.4%, 33). A further 19% (12) responded by describing the site as ‘very effective’. However, 14.3% (9) recorded an unsure response, with 12.7% (8) describing the site as not very effective and 1.6% (1) as not effective at all. A number of respondents described the site’s use of flash as distracting, ‘Keep the graphics simple. Concentrate on ideas first before adding any animations as these often can detract

from the main messages' (respondent 81, Appendix M). Others indicated the site's use in helping clients to understand the industrial design process and the designer's role and responsibilities, 'It's great what you have created especially from my designers view. I wonder if client's can/will value such a tool or visual guide of the process' (respondent 19).

Question 6 asked respondents about the ability of IDsite to foster understanding of the ways design tools may support the design process and the practice of designers with different levels of expertise (Figure 43). Respondents were asked to check as many categories as they thought applied:

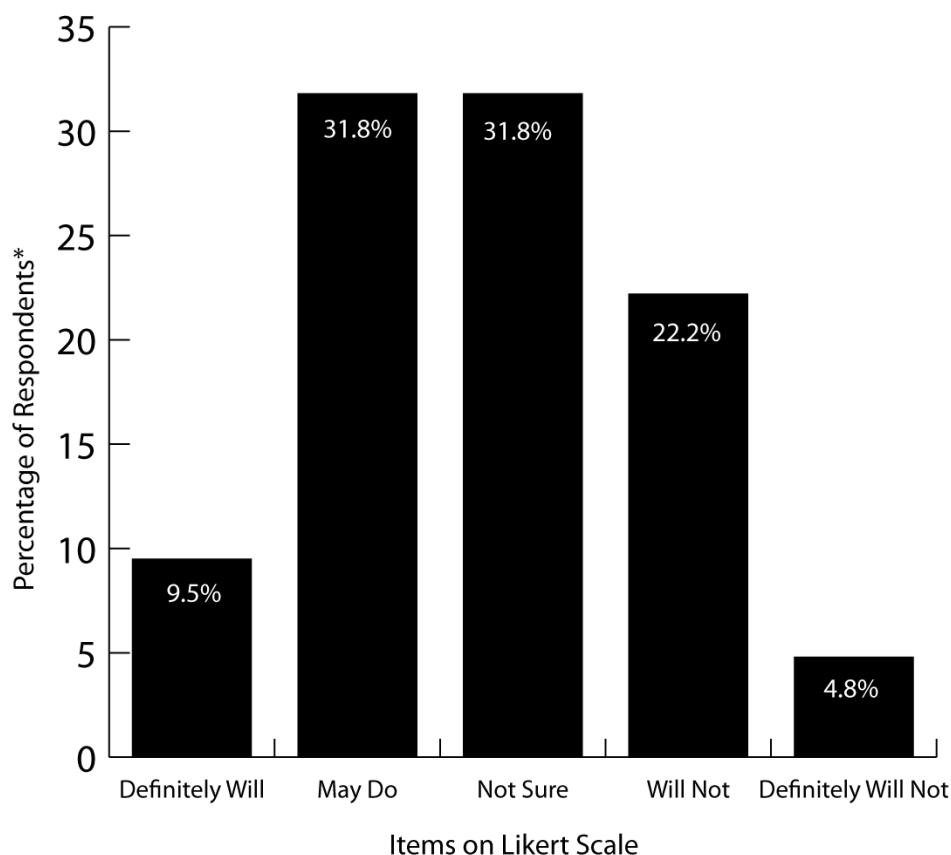


*61 Responded and 30 skipped this question

Figure 43 Q6 Would the site help any of the following groups better understanding the role design tools play in support of the design process?

73.8.% or 45 respondents felt IDsite most suited in supporting undergraduate design students in their use of design tools. A further 67.2% (41) recorded novice designers as potentially benefiting from the site. 41% (25) suggested postgraduate students may find the site effective, and 36.1% (22) indicating design educators may use the site. The items design researchers (24.6%, 15), mid-weight designers (19.75%, 12) and experienced designers (9.8%, 6) registered fewer responses respectively. Results indicated the sample felt IDsite would be most suited to an audience of novice and student designers. Responses to the open-ended question 8 also suggested some designers considered the tool helpful in developing client understand of the design process, 'I am going to use this to help explain how the process should be done' (respondent 85, Appendix M).

Question 7 asked respondents about IDsite’s ability to foster understanding of the respondent’s own use of design tools during the design process. Responses to this last Likert-scale question were varied across the 5 items of the scale (Figure 44):



*63 Responded and 28 skipped this question

Figure 44 Q7 Would IDsite help you to better understanding relationships between the design tools you use and their support of the various requirement of the design process?

31.8% (20) registered a response of ‘may do’ when asked of the site’s ability to support one’s own use of design tools. An identical percentage recorded a response of not sure (31.8%). 22.2% (14) suggested the site would not support their understanding of design tools, with a further 4.8% (3) recording a response of ‘defiantly will not’. Given the level of experience the sample group possessed (results, Questions 2 and 4), the sample was weighted towards designers with experience of practice. These designers seemed to consider IDsite more effective in supporting student and novices (Question 6). As such, it is less surprising respondents considered the site less effective in supporting their own use of design tools. This was born-out in some of the feedback gathered in response to the open-ended question 8, ‘Quite a good website, I might recommend it to undergraduates’ (respondent 77).

Overall, findings from the survey of designers provided some positive feedback on IDsite’s effectiveness in supporting designers in their engagement with design tools. The results indicated the site’s use with novice and student designers as particularly beneficial. Although findings indicated concern over the site’s presentation of

information and IDsite’s flash-based approach to communication, a majority of respondents recorded positive responses to questions asking of the site’s ability to foster understanding of the use of design tools. This was seen in responses suggesting positive attitudes towards the accuracy of the model of the design process (Question 5), the effectiveness of IDsite in describing the relationship between design tools and their use in support of the design process (Question 6).

Data Collection from Student Focus-Group

A second stage of validation involved a focus group of 20 undergraduate students at Kingston University’s Faculty of Art, Design and Architecture, School of 3D Design. All student participants were in the second year of a three year degree and were drawn from two undergraduate courses: BA Product & Furniture Design and BSc Product Design. In phase 1 of IDsites validation an online survey was used as a research instrument, the first 4 questions of which were design to gather data on the attributes of participant respondents. Because the researcher had prior knowledge of the students’ background and level of experience, initial attribute questions were omitted from the focus group meeting. Table 3 summarises student sample attributes:

Course Title	Year of Study	Number of Participants
BA Product & Furniture Design	2 nd Year	13 Students
BSc Product Design	2 nd Year	7 Students

Table 3 Student attributes within the focus group

At the start of the session, the researcher introduced himself and spent a few minutes outlining the aims of the doctoral study. IDsite was then introduced as a tool to support designers in their engagement with and use of design tools during studio practice. The site was then presented with the use of a large screen. Each participant was seated behind a computer terminal. At this point the researcher took care not to prescribe or dictate the tool’s use. Instead an overview of navigation features was presented. Following this the students were asked to spend a short time reviewing the site and handed a survey to complete whilst doing so (Appendix K). The survey questions aimed to gather feedback on the students’ attitudes to IDsite (Table 4):

4 Questions to Gather Data on Practitioner Attitudes	Response Items on Scales				
Q1: Looking at IDsite’s homepage, how accurate is the model of the design process?	Very Accurate	Somewhat Accurate	Not Sure	Not very Accurate	Not Accurate at All
Q2: Do you find the images and text effective in helping to describe design tools and their relationship to the design process?	Very Effective	Somewhat Effective	Not Sure	Not very Effective	Not Effective At All
Q3: Would the site help any of the following groups better understanding the role design tools play in support of the design	Undergraduate Students				
	Novice Designers				
	Postgraduate Students				

process? (check all that apply)	Design Educators				
	Design Researchers				
	Mid-weight designers				
	Experienced designers				
Q4: Would IDsite help you to better understanding relationships between the design tools you use and their support of the various requirement of the design process?	Defiantly Will	May Do	Not sure	Will Not	Defiantly will Not

Table 4 List of attitude questions and items on response scales

As with the online survey above, a final open-ended question provided an opportunity for the students to provide feedback:

- Finally, please use this space to provide any further observations or suggestions to help us improve IDsite.

At the end of the session the students were asked again about the effectiveness of IDsite in a short Q&A session where the students were encouraged to speak freely. Completed surveys were then collected in and the session concluded.

Focus Group Results

As with the first phase validation above, phase 2 presents results as percentage responses to each of the questions presented in table 19 above. This was achieved through calculating the sum of responses to each item within each of the four questions and dividing this figure by the total number of respondents. This then gave a percentage response for each item. This percentage was compared to the survey findings at phase 1 of IDsite’s validation.

Student survey Question 1 sought to gather responses to the model of design process presented on the site’s homepage. Figure 45 presents focus group findings alongside with those of the online survey at phase 1 of validation:

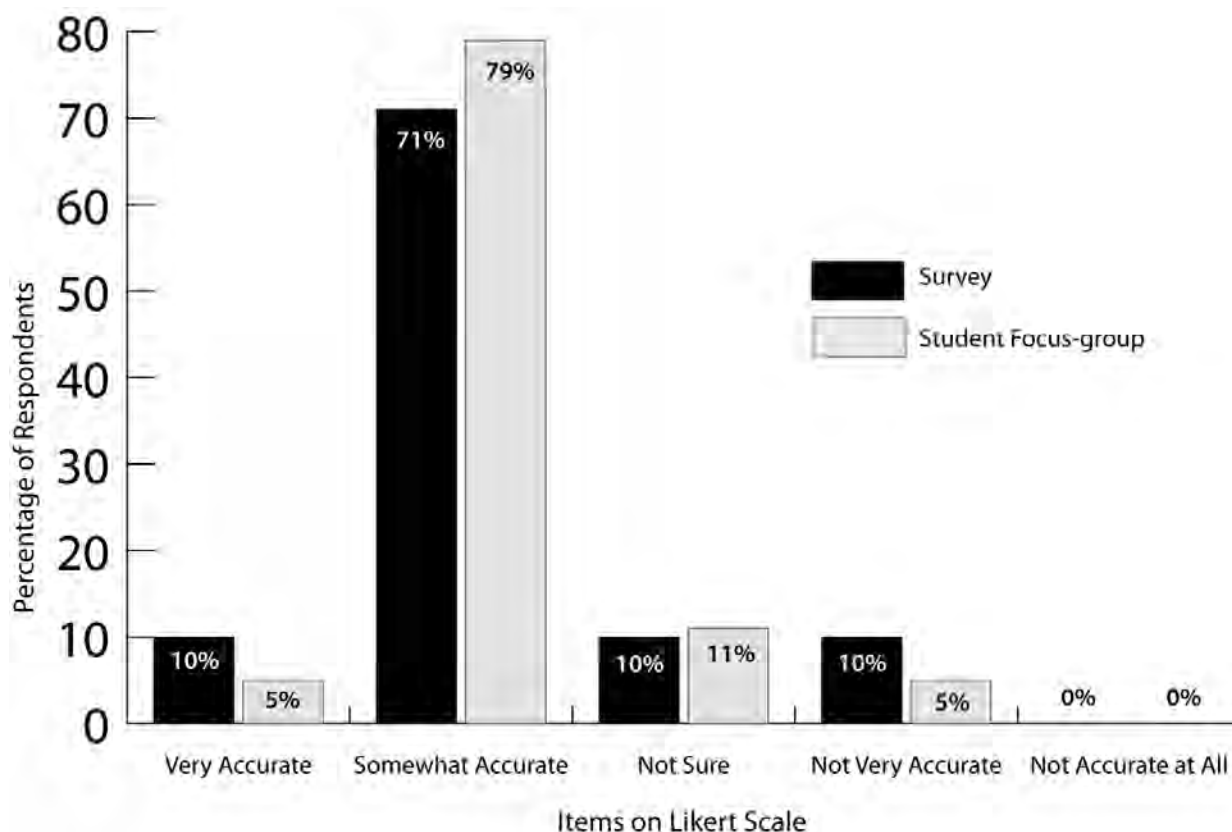


Figure 45 Looking at IDsite’s homepage, how accurate is the model of the design process?

79% of the student focus group recorded a response of ‘somewhat accurate’ when asked about the model of ID process. A further 5% described the model as ‘very accurate’, with 11% ‘unsure’ and a further 5% describing the model as ‘not very accurate’. Comparing the student responses to those of the sample taken during first phase validation (dominated by experienced design practitioners) there was little significant difference between responses. A majority of both groups recorded a response of ‘somewhat accurate’. Some of the student participants voiced concerns over the complexity of the model and the ability of non-designers to understand it, ‘This illustration (sketch of model of design activity) might need slightly more explanation for non-designers to understand’ (Students 14, Appendix M).

Question 2 asked students about the effectiveness of text and images in their ability to describe design tools and their relationship to the model of design process presented on IDsite’s homepage (Figure 46):

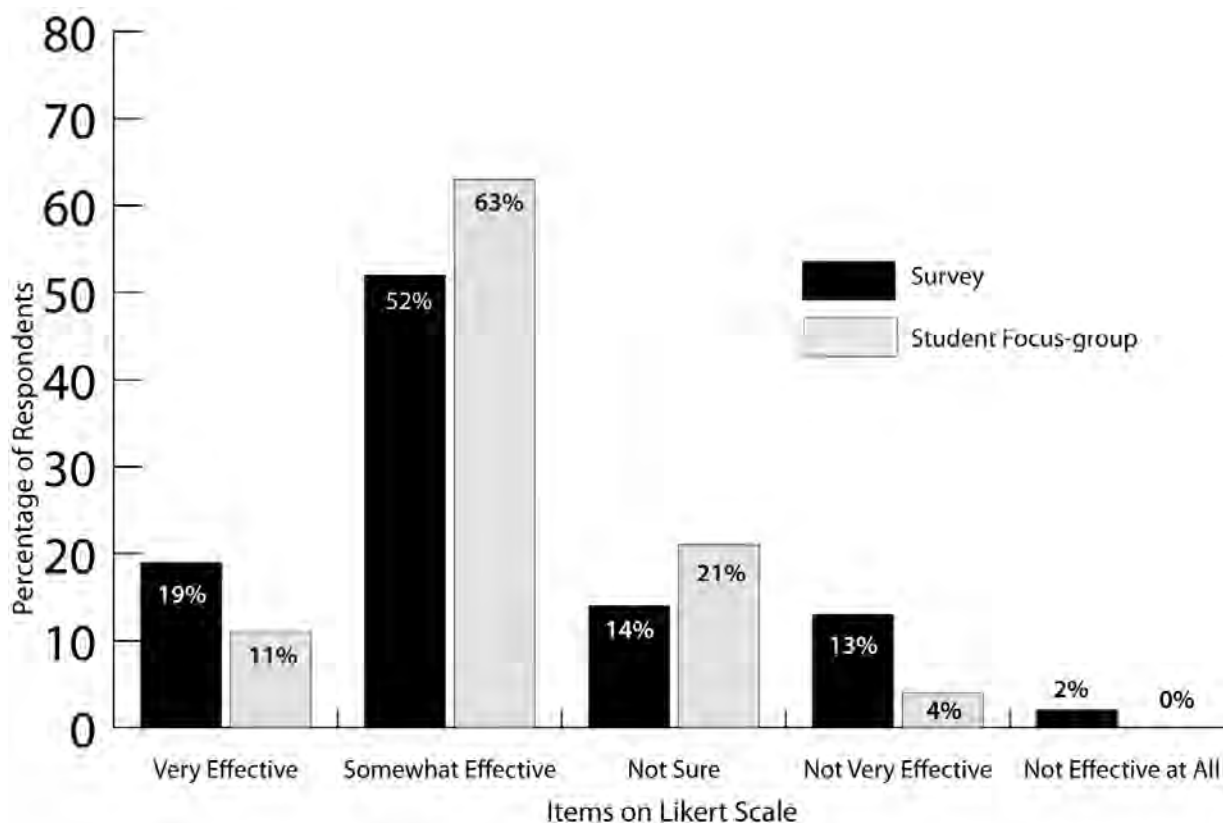


Figure 46 Do you find the images and text effective in helping to describe design tools and their relationship to the design process?

A majority of the student group responded positively to the site’s use of text and images (63%). This was slightly higher than the findings from phase one of validation (52%). However, a smaller percentage of students recorded a response of very effective (11%), compared to the phase one survey (19%). A greater percentage of students responded with not sure (21%), but fewer recorded a response of not very effective (4%), compared to 13% of the first phase sample. As with responses to question 1 (Figure 9.46), little significant difference was seen in responses across the two phases of validation. Some students suggested concern over IDsite’s complexity in the presentation of information, ‘The pages are quite busy & make it hard to focus on what you actually need to read.’ (Student 7, Appendix M). However, others were more positive in their response to the site’s presentation of information, ‘I really like this website. I think it also gives people who don’t really know what ID is a very good understanding of ID’ (Student 5). With some concern for the amount of information presented, the focus group findings, like those of the sample at phase one, indicated a positive response to IDsite’s use of images and text.

Question 3 asked how useful the sight might be to designers of different levels of expertise, at different stages in their careers (Figure 47):

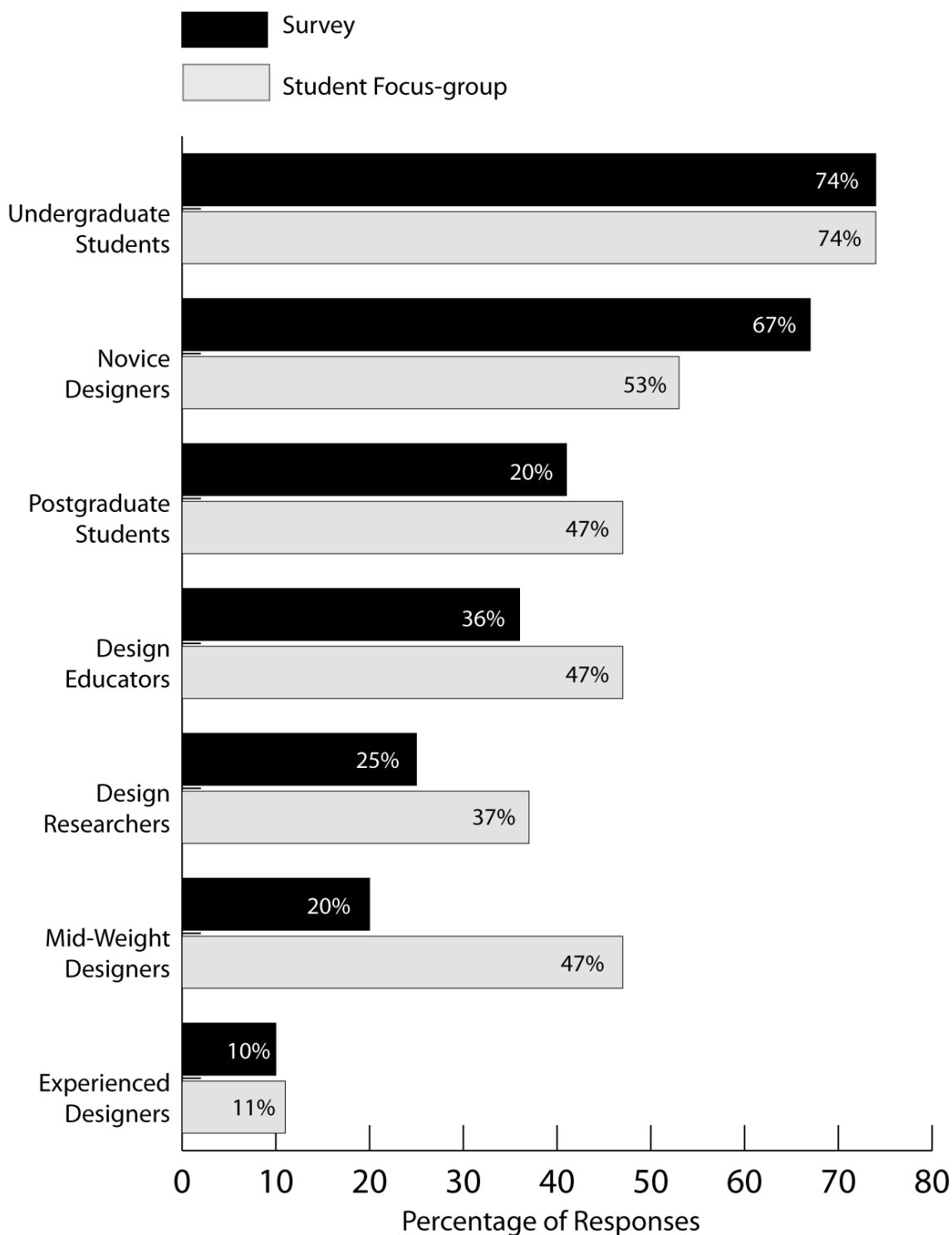


Figure 47 Q3 Would the site help any of the following groups better understanding the role design tools play in support of the design process? (Check all that apply)

As with phase 1, results indicated a majority of the student group considered undergraduate students as the most likely group to benefit from IDsite (74%). Fewer recorded a response of novice designers (53% compared to 67% at phase 1). Unlike the online survey a greater percentage of students considered more experienced designers and academics as benefiting from the site (postgraduate students 47%,

design educators 46%, design researchers 37%, mid-weight designers 47%). Like findings from the 1st phase however, results suggested students' considered experienced designers as least likely to benefit from IDsite. The strong responses to IDsite's target audience (undergraduate students and novice designers), goes some way in validating IDsite as a tool for students and those designers at the start of their career. The stronger student responses towards those groups with more experience suggests the students see the site as more effective in supporting designers at various stages of their careers.

Question 4 asked the student focus group of the ability of IDsite to support their own use of design tools during studio practice (Figure 48):

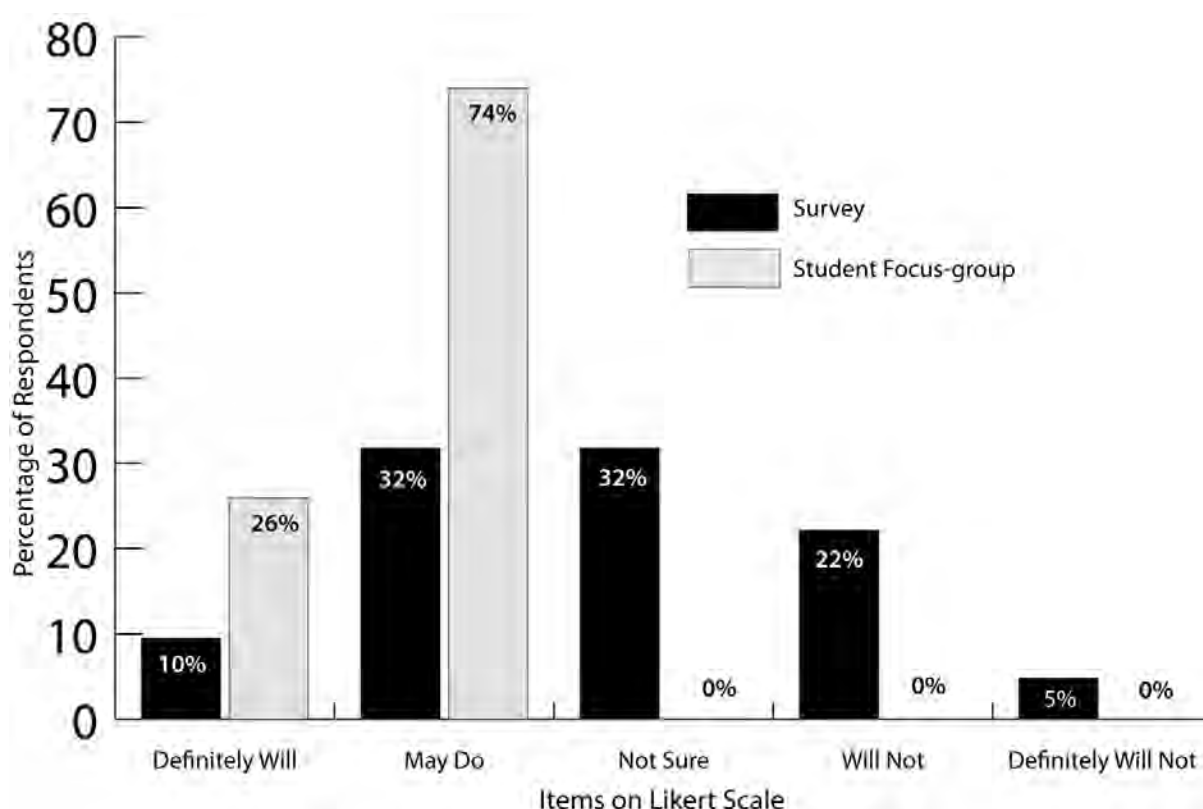


Figure 48 Q4 Would IDsite help you to better understanding relationships between the design tools you use and their support of the various requirement of the design process?

The difference between the sample at phase 1 and the student sample was significant. A large majority (74%) of students recorded a response of 'may do' when asked of IDsite's ability to support their own understanding of design tools. A further 26% recorded a response of 'defiantly will'. This was in contrast to the 1st phase results indicating 10% responded by recording a response of 'defiantly will'. Only 32% of the 1st phase sample responded 'may do', with a further 32% responding 'not sure', 22% 'will not' and 5% 'defiantly will not'. The more positive student responses indicated the sample see the site as effective in fostering understanding of design tools and their use in support of studio practice compared to designers with greater experience. This is important for IDsite's validity as a tool aimed at supporting students of design and less

experienced design practitioners. These more positive student response were also born out through discussion with the students at the end of the focus group and through comment left in response to open-ended question 5, 'It is a really interesting web. Including many information' (Student 4, Appendix M).

Discussion

Appendix O has described the embodiment of research results within a design tool (IDsite). The site aimed to communicate research outcomes using a highly visual and interactive web-site, through which designers may explore relationships between design tools, the various requirements of studio practice and the character of design activity.

Survey and interview results (Thesis Chapters 7 & 8) identified a relationship between designer expertise and approaches to practice that relates to the divergent/convergent model of the design. In response to this IDsite attempted to provide a platform for understanding the rich and complex activity of industrial design; how the use of tools and the designer's own idiosyncratic approach has influence upon design activity during studio practice; and the final specification of design intent.

Validation of the site has suggested, although the approach to research dissemination was seen as significant and relevant, challenges remain in the design of the resource and its ability to communicate research clearly. Going forward, in the development of IDsite, the researcher will work to address these concerns. Although the digital resource is seen as a developing design tool, it represents an example of how innovation in research knowledge dissemination can be used to engage an audience of design practitioners.

The validation studies presented here indicate the site requires more work in terms of the presentation of information and user interface to further develop the site as a tool to support studio practice. However, the studies have indicated the site's potential as a resource to support less experienced designers in their understanding of design tools. The approach to research dissemination has the potential to facilitate improved engagement with a practice orientated audience. Whilst acknowledging the role of more conventional methods of dissemination, more relevant approaches to the articulation and exchange of design research knowledge are required. These approaches call for innovation in knowledge dissemination that exploits the highly visual language of design in order to best engage practice.

- END OF REPORT -