Industrial Design Tools and Design Practice

An approach for understanding relationships between design tools and practice

James Self*, Professor Hilary Dalke*, Dr. Mark Evans**

**School of Design, Kingston University London*
K0729860@Kingston.ac.uk
*** Loughborough University, Department of Design and Technology*
M.A. Evans@lboro.ac.uk

Abstract: Design representations are constructed by designers using design tools, from pencils to interactive graphics tablets and rapid prototyping technologies. These tools are employed to externalise, develop and communicate design intent during professional practice. With an expanding inventory of media employed by the designer, this research provides a framework for understanding the critical role design tools play during a period of practice, and how that role is influenced by their idiosyncratic characteristics. The Framework consists of two constructs. Firstly, a taxonomy categorises Design Tool Types within a model of industrial design practice that progresses from concept to development and finally detail design. Secondly, 5 Universal Design Tool Characteristics measure the character of these Design Tool Types. In order to validate the Framework a survey of design practitioners was conducted. Results suggest tools, used for a similar purpose during practice; concept, development or detail design, share common characteristics and that the Framework is valuable as an analytical approach to understanding the tacit effectiveness of design tools. This understanding goes some way to make implicit relationships between design tools and design practice explicit.

Keywords: Industrial Design Tools, Design Tool Characteristics, Design Practice

1. Introduction

Industrial designers use an expanding inventory of digital and conventional design tools during their design practice [11, 25, 29], helping designers to visualise, communicate and develop design ideas [11, 12] . With an expanding array of tools available, the design practitioner's understanding of the benefits of individual tools is important [7, 9, 21]. The ability of the designer, influenced by experience of practice, to use the right tool in the conceptualisation, development and detail of design is critical [32].

The designer must consider the tool's affordance in the context of the purpose of its use. The literature reviewed raises valuable questions. How will the tool communicate ideas? [9]. How clear or ambiguous do these communications need to be? [11, 30]. Is the tool required to generate a variety of ideas or the progression of a few? [11, 36] How much detail is required, [3] or commitment to an idea will the use of the tool communicate? The risk in neglecting to consider the character of the design tool and how this influences practice, may lead to miscommunication, the unsuitable representation of design ideas and early fixation [11].

2. Aims of the Study

This study aims to make explicit the tacit characteristics of design tools and to describe how these characteristics relate to design practice. An analytical Framework was constructed and used as the vehicle to explore the tool character/practice paradigm, with a survey of design practitioners employed as validation of the Framework's effectiveness. Results suggest the Framework can be used to analyse and make explicit the tacit characteristics of design tools. And that the Framework goes some way in understanding how these characteristics relate to the tool's effectiveness in supporting industrial design practice, helping designers make more informed decisions when selecting design tools to support practice.

3. Design Tool Characteristics: The Concept Sketch as Example

A body of work exists describing the character and role of sketching during design practice. These studies suggest that, in addition to being useful for communicating design ideas to others, the sketch allows 'conversation' between designer and design representation [11, 20, 22]. This conversation supports the emergence of ideas and their fluid progression during design practice [12]. The sketch, significantly, enables design ideas to be ambiguously represented, making sketching useful for conceptual design [9, 11, 13]. The sketch affords Lateral Transformations; that is the ability to move from one design idea to another [11]. The character of the sketch, 'does not force the designer to pay attention to detail that he is not yet ready to consider' [3]. The sketch, as design tool, allows an overview of the bigger picture, a required imprecision. It is only when design practice progresses, when conceptual design moves towards development and then onto detail design, that precision increases and different tools are employed to support this change [29]. Prior work on the design sketch suggests the sketch's character is critical in supporting the purpose of practice; to conceptualise, for example.

4. Framework for Analysing the Character of Design Tool Types

Industrial design practice consists of problem structuring, concerned with the identification and development of the design problem and problem solving, concerned with the generation of solution ideas. The designer uses physical embodiments of ideas in the form of drawings, illustrations, models, digital media and prototypes to support practice and help develop solutions to the design problem [9]. These design representations are of products and artifacts that do not exist, but attempt to embody and communicate a model of their intended form and structure. The Framework analyses the effectiveness of the tools used to construct these representations.

The Framework for analysing design tools has two constructs: Construct I: 5 Universal Tool Characteristics or UTC's *(used to describe the character of design tools)* and Construct II: A Taxonomy of Design Tool Types or DTT's *(used to describe 11 generic types of media through which industrial designers' embody their ideas)*. The Taxonomy is based upon a 3 stage model of practice, categorising DTT's within these 3 stages (fig 1, p4). This Framework is used to examine the relationship between the character of DTT's, through examining their UTC's, and the tool's support of practice. Taking again the conventional sketch as an example, the UTC's of the DTT 'sketch', as medium for the representation of design ideas, make it useful for 'concept' design practice [19].

4.1 Construct I: 5 Universal Tool Characteristics (UTC's)

The 5 UTC's were identified through literature review of prior work on design tools and representation [3, 9-12, 18, 25, 30, 33, 36], and are presented below with brief descriptions and location in literature:

Table 1: The 5 UTC's (Universal Tool Characteristics), descriptions and Terms of reference

Characteristics	Descriptions (of UTCs)	Terms of Reference	
1. Modes of Communication	How the design tool supports communication of design ideas to others How the design tool supports self-reflection and the emergence of design ideas	Dorta [9]	self-reflective mode
		Schon [30]	representation, analysis, emergence
		Goldschmidt [14]	dialogue with self
		Johnson [18]	I-representations
2. Levels of Ambiguity	To what extent the design tool supports the ambiguous representation of ideas To what extent the design tool supports the unambiguous representation of ideas	Fish [10]	vagueness
		Goldschmidt [14]	Unstructured nature
		Goel [11]	Ambiguity/ Density
		Vessel [36]	unspecific
3.Transformational Ability	To what extent the design tool supports movement from one design idea to a new idea – horizontal transformations To what extent the design tool supports movement from one idea to a variation of the same idea – vertical transformations	Goel [11]	Transformation
		Visser [36]	duplicate, add, detail, concretize, modify, revolutionize
4. Levels of Detail	To what extent the design tool supports a high or low level of detail To what extent the design tool supports an overall or artistic impression of form detail	Brereton [3]	kinds of information available
		Visser [36]	precision
		Goldschmidt [13]	Less/more specific
5. Levels of Commitment	To what extent the design tool communicates a high or low level of commitment to design ideas	Goel [11]	Early Crystallisation/ completeness
		Pipes [25]	More Committed
		Powell [26]	less committed
		Tovey [33]	uncommitted/ more committed

4.2. Definitions of Universal Tool Characteristics (UTC's)

1. Modes of Communication: The concept sketch is used to communicate with ones-self in a reflective activity and/or with others during collaborative design [9]. Later representations are used to communicate intention to others. Mode of communication refers to the ability of the design tool to support self-reflective and/or third party communication. **2. Levels of Ambiguity:** Ambiguity is tied to the DTT's ability to afford the reflective emergence of varied design ideas or, constrain an unambiguous embodiment of ideas. The Ambiguous and unstructured nature of a design representation can support reinterpretation of design ideas [14]. **3. Transformational Ability:** Ambiguity supports Lateral Transformation, the designer is able to move from one idea to another, 'if ambiguity is not afforded by the medium of representation then transformation proceeds vertically; moving from one design idea to a variation of the same idea' Goel [11]. Visser [36] distinguishes different forms of transformation: duplicate, add, detail, concretize, modify, revolutionize. **4. Levels of Detail:** The ability of the DTT to support the expression of information, 'Different representations make different kinds of information available' Brereton [3]. Visser [36] describes detail as precision and suggests, at the front end of practice, designers require the imprecision tools such as sketching allow, 'Only gradually, as design progresses, are initial representations translated into representations with increasing degrees of precision' (ibid). **5. Levels of Commitment:** Level of Commitment is a tension between two desires, a designer's wish not to crystallize design ideas too soon and to communicate ideas, working them towards a solution [11]. Levels of Commitment refer to a DTT's ability to communicate ideas that appear more or less committed.

4.3. Construct II: Taxonomy of Design Tool Types

The second construct in the Framework is the Taxonomy of DTT's. Literature review of existing models of practice, [2, 4-5, 16, 11, 25-26, 31, 35], new product development, [27, 28] the taxonomy of design tools and representations, [3, 24, 32] and accounts of design tool use in practice, [3, 8, 12, 15, 25, 27, 33-34] were used to inform the Taxonomy (fig 1).

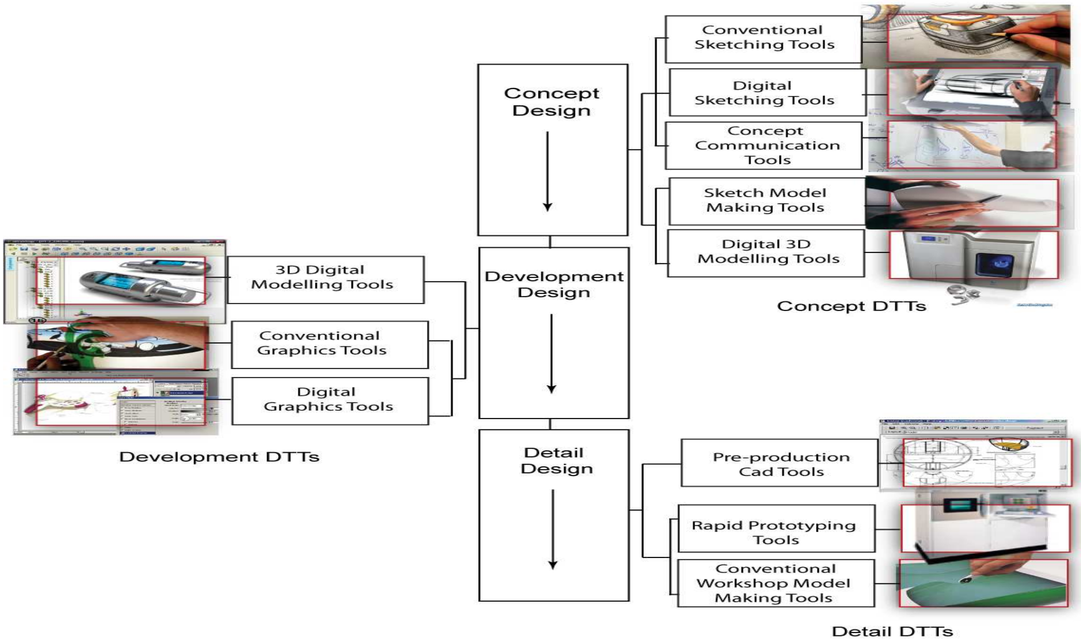

Figure 1: Taxonomy of 11 Design Tool Types (DTT's) around 3 stage model of practice

4.4. A 3 Stage Model of Industrial Design Practice

A large number of existing models of industrial design practice were identified as having 3 generic stages, with various terms used to describe these stages, (Table 2). This 3 stage model of design practice: concept design, development design and detail design, was used as the bases of the taxonomy of 11 DTT's (Fig 1).

Table 2: Terms used to describe 3 stage models of practice

References	Terms used to Describe Practice		
	Concept Design	**Development Design**	**Detail Design**
Cross [4]	Concept	Embodiment	Detail
Pipes [25]	Concept generation	Design development	Specification
Ulrich [35]	Concept	System level	Detail
Geol [11]	Preliminary	Refinement	Detail
Baxter [2]	Concept	Embodied	Detail
Press et al [27]	Concept	Prototype development	Final design

Of course, design practice is iterative and DTT's are used between these three stages. However, there is a fundamental progression of design towards a final, detailed solution idea [27]. With this progression, different DTT's were identified as used to support the 3 stages in practice [11, 25, 29]. This model was employed in order to inform the Taxonomy, placing DTT's in terms of their principal purpose of use: to conceptualise, develop or detail design ideas.

The Framework for analysing the character of DTT's now had two constructs: the UTC's (I) and the Taxonomy of DTT's (II). Using the Framework a survey was designed to gather data on designer attitudes towards the Universal Tool Characteristics of the 11 DTT's identified in the Taxonomy. This survey was intended to test and validate the Framework as an approach to analysing the character of tools and their relationship to practice, drawing out any contradictions and uncertainties.

5. Survey

The use of surveys is common in design research wishing to collect a large data set [1, 17, 23], with the survey representative of a large sample of designers. Invitations to complete the survey were sent to industrial design consultants in the UK, US, Netherlands, South Korea, Canada, Ireland and Australia. Designers were contacted and a 15% response rate of 49 was achieved and analysed. A pilot test was sent to the potential respondents to test the question design and survey structure. As a result of the pilot, the survey was reduced and divided into three shorter surveys.

5.1. Survey Question Design

The first section consisted of 5 questions designed to gather information on the respondent's attributes; company or consultancy, qualifications, designer discipline, working environment and experience. The designers were then asked 8 questions on the character of DTT's relating to the 5 UTC's. Table 3 presents the 8 questions along with the UTC's they were designed to measure. Responses to these 8 questions were registered using a five point Likert scale [6], whereby the following response values were given: *Strongly Agree (+2); Agree (+1); Neutral (0); Disagree (-1); Strongly Disagree (-2).* At the end of the survey an open-ended question was used to gather qualitative responses.

Table 3: The 8 Survey questions and UTC's measured

8 Questions to measure 5 Universal Tool Characteristics (UTC's)	**UTC's Measured**
Q1.The design tools listed below are useful for: Representing the engineering detail of design ideas: Do you agree or disagree?	**Levels of Detail** To what extent the design tool affords a high or low level of specific detail.
Q2. The design tools listed below are useful for: Representing the artistic/creative form of design ideas: Do you agree or disagree?	**Levels of Detail** To what extent the design tool affords an overall or artistic impression of detail.
Q3. The design tools listed below are useful for: Representing design ideas in a more constrained, unambiguous way: Do you agree or disagree?	**Levels of Ambiguity** To what extent the design tool affords design ideas to be represented unambiguously
Q4 The design tools below are most useful for: Design work that can move easily between design ideas (Lateral Transformations): Do you agree or disagree?	**Transformational Ability** To what extent the design tool affords movement from one design idea to a new idea – horizontal transformations.
Q5 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?	**Transformational Ability** To what extent the design tool affords movement from one idea to a variation of the same idea – vertical transformations
Q6 The design tools below: Communicate a high level of commitment to design ideas: Do you agree or disagree?	**Levels of Commitment** How the design tool communicates a high or low level of commitment to design ideas.
Q7 The design tools below are more useful for: Communicating design intentions to others: Do you agree or disagree?	**Modes of Communication** How the design tool affords communication of design ideas to others.

Q8 The design tools below: Aid self reflection and the dynamic generation and evolution of design ideas: Do you agree or disagree?	**Modes of Communication** How the design tool affords self-reflection and the emergence of design ideas

5.3. Results

Each returned survey resulted in values, based on the 5 UTC's, expressing the designers' attitudes towards the DTT's they used in practice: 8 values for each of the 11 DTT's identified in the Taxonomy; a total of 88 values ranging from +2 (Strongly Agree) to -2 (Strongly Disagree). Each of the returned surveys was then combined to calculate 8 overall values for each of the 11 DTT's. The 11 DTT's are grouped into 3 categories, concept design, development design and detail design, relating to their place within the Taxonomy of design tools (fig 1). Figures 2 to 6 show graphs of results for questions 1, 3, 4, 6 and 8 (see table 3 for further description of these questions).

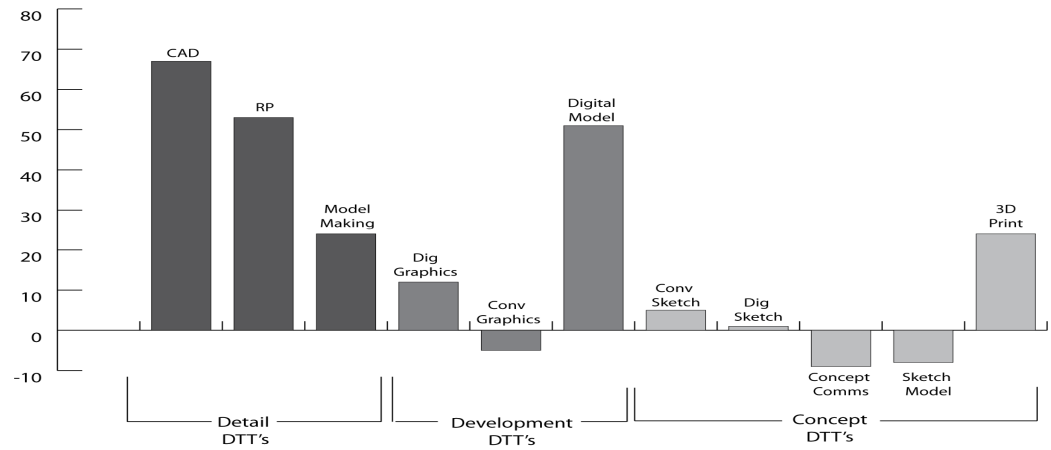

Figure 2 Q1: Levels of Detail (UTC4)

Q1: The DTT's ability to support detailed specification. CAD and RP scored highly (67, 51) Workshop Model Making (24). Concept DTT's showed lower values (3, 1,-9,-8) except 3D printing (24). Digital Modelling higher (24), Conventional Graphics tools were negative (-5). **Q2**: The DTT's ability to construct representations showing less detail. Concept DTT's rated highly: (45, 55, 36, 32, 20), as did development DTT's (49, 45, 44), CAD lower (-1), RP and Model Making higher (51, 24).

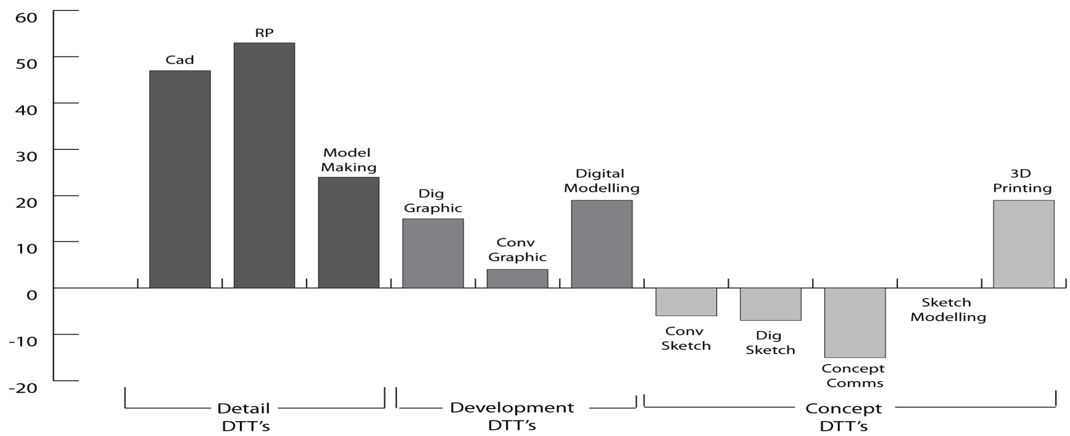

Figure 3 Q3: Levels of Ambiguity (UTC2)

Q3: The DTT's ability to mediate design ideas in an *unambiguous* way. Concept DTT's were negative, (-6, -7, -15, 0), except 3D Printing, (14). Detailed DTT's were valued highly. Development DTT's middling (15, 4, 19).

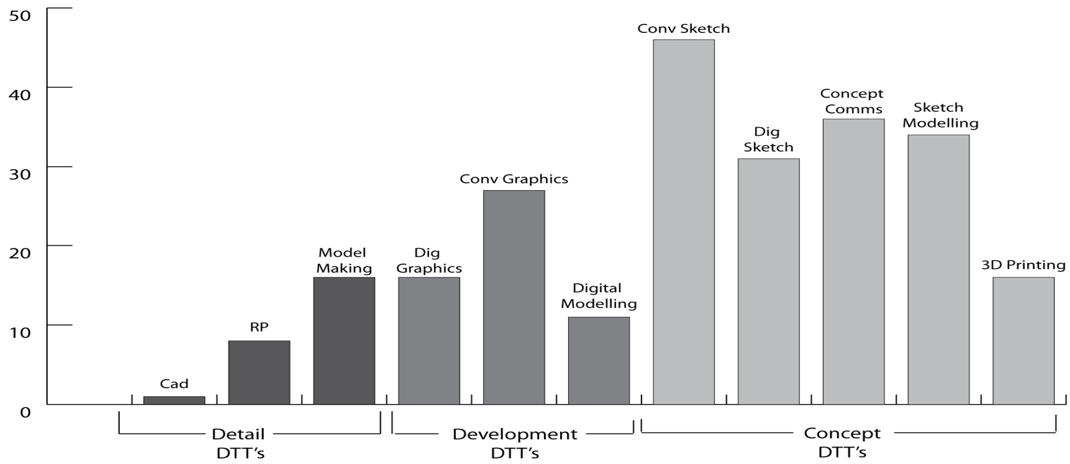

Figure 4 Q4: Transformational Ability (UTC3)

Q4: DTT's ability to support lateral transformations (UTC3). Concept DTT's, with the exception of 3D Printing, were valued highly (46, 31, 36, 34, 16). Development DTT's showed middling values, (16, 27, 11); detail DTT's lower, (1, 8, 16). **Q5**: DTT's ability to support vertical transformations (UTC3). Concept DTT's again scored high, (35, 35, 32, 31, 21), as did development DTT's (32, 28, 30). Detail DTT's lower (26, 20, 16).

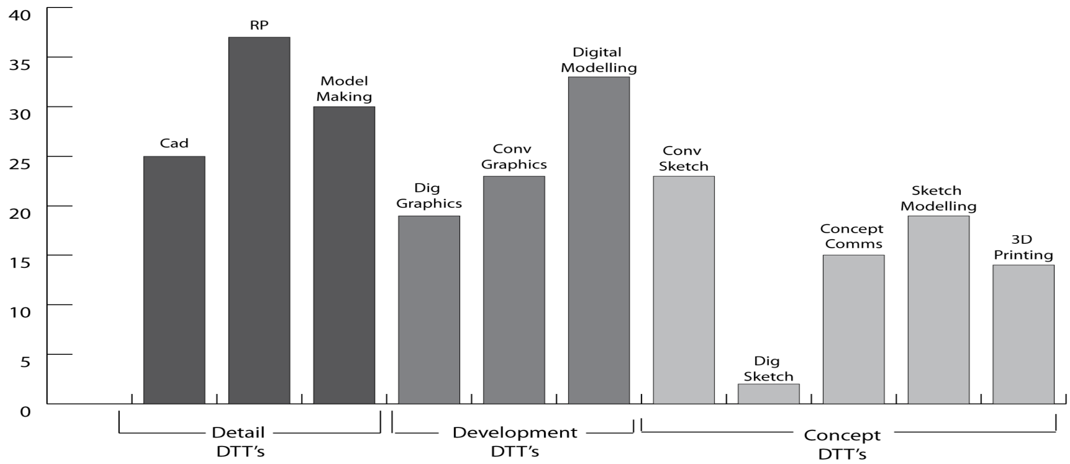

Figure 5 Q6: Levels of Commitment (UTC5)

Q6: DTT's communicating high level of commitment (UTC5). Detail DTT's and Digital Modelling showed higher values, (25, 37, 30, 33), Conventional and Digital Graphics tools slightly lower (23, 18). Concept DTT's, generally, were lower (23, 2, 15, 19, 14). With exceptions values increased from concept through detail design.

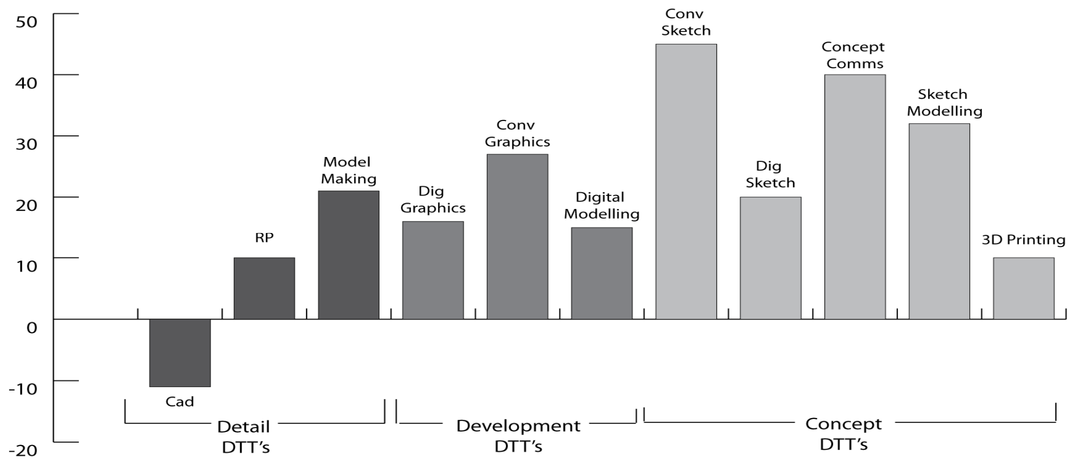

Figure 6 Q8: Modes of Communication (UTC1)

Q8: DTT's ability to aid self-reflection (UTC1). Concept DTT's resulted in higher values, exception 3D Printing and Digital Sketch; (45, 20, 40, 32, 10). Development DTT's valued (16, 27, 15). Detail DTT's (-11, 10, 21). With exceptions, the character value trend decreased from concept to detail design. **Q7**: Communicate ideas to others (UTC1). Results showed little variation through concept, development and detail design.

6. Discussion

Results confirm different DDT's support the representation of different levels of detail (Q1/UTC4) and that this support is related to the tool's use at different stages in practice; CAD's ability to support high levels of detail during detail design, the sketch's ability to support idea generation, requiring less detail, during concept design. When asked about the representation of less detail (Q2/UTC4), designers considered all design tools, bar CAD, to support creative form. These results suggest level of detail in representation is useful as a measure of a DTT's ability to support a stage in practice and that all representations specify form, but at different degrees of detail. This validates UTC4 as useful in analysing the tool's ability to support a stage in practice in terms of its capacity to afford more or less detail. With regards the Framework, terms used to describe UTC4 need to reflect the kinds of form represented by the DTT's and how this might relate to the levels of detail within the representation.

Results for (Q3/UTC2) show a decrease in the tool's support of ambiguous representation as practice progresses through concept, development and detail design. This indicates the clear relationship between levels of ambiguity and stage in practice. Analysing a tool's ability to support more or less ambiguous representation in terms of concept, development and/or detail design practice results in a clearer understanding of its effectiveness.

Lateral transformation, as a characteristic of design tools (Q4/UTC3), typically decreased through concept, development and detail design. Interestingly, designers rated convention sketching, sketch modelling and graphics tools significantly higher than their digital counterparts. This may indicate intriguing differences in human-computer and conventional interaction; more work is required. The trend for the tool's effectiveness, in supporting lateral transformation, to decrease as design progresses demonstrates a relationship between lateral transformation and stage in practice. This relationship was again indicated by the tool's ability to support vertical transformations (Q5/UTC3) decreasing during concept through detail design practice. These results imply the effectiveness of a design tool can be made explicit through the analysis of its ability to afford lateral and/or vertical transformations; the former being effective during conceptual design, the later of more use later towards development and detail. These results help validate the analysis of lateral and vertical transformations to access a tool's ability to effectively support concept, development and detail design practice.

Results indicate DTT's are characterised by an ability to support stronger commitment as design progresses (Q6/UTC5). However designers also considered sketching to be characterised by an ability to afford strong levels of commitment. This suggests some DTT's may communicate a weaker or stronger level of commitment dependent upon the use the designer makes of them. This may also indicate greater flexibility in some tools' ability to support different stages in practice, with others characterised by a more defined role. The Framework may require refinement to reflect the apparent versatility of some tools against the more specific use of others.

Results suggest concept design tools are characterised by an ability to support self-reflection (Q8/UTC1), with the importance of this reflective character decreasing as design progresses. When asked of the tool's ability to communicate with others (Q8/UTC1), results showed more modest differences; unsurprisingly all representations communicate with others. Analysing a tool's ability to support self reflection will indicate its effectiveness in terms of conceptual, developmental and/or detail design. However, in terms of communication with others, consideration must be made as to the kinds of communications requires and how this may relate to the stage in design practice.

7. Conclusions

A literature review came to the hypothesis the idiosyncratic character of design tools influence the tool's effectiveness in support of design practice. In response a Framework for analysing the character of design tools was developed. The Framework consisted of 2 constructs: 5 Universal Tool Characteristics (UTC's) to analysis the character of design tools. And the taxonomy of Design Tool Types (DTT's) within a 3 stage model of design practice. In order to help validate the Framework it was used to design a survey of practitioners. The survey analysed 11 Design Tool Types in terms of their universal characteristics (UTC's) and their use during design practice. Results of the validation survey indicate the Framework is valuable as an analytical approach to understanding the tacit effectiveness of design tools. And that the Framework goes some way to make the implicit relationships between design tools and practice explicit. The results also indicate some interesting areas of refinement within the structure of the Framework. For example, the influence of the designer's idiosyncratic use of design tools in terms of the tool's universally accepted character, the apparent versatility of some tools against the more defined use of others and the influence of detail in terms of the representation of form.

Future work will include the use and refinement of the Framework through exploration of the idiosyncratic attitudes designers of different levels of experience have towards the tools they use. And the investigation of the versatility of some design tools over the apparently more defined use of others.

Acknowledgments

The authors would like to acknowledge the contribution of the designer participants and that of Laura Stott.

References

[1] ARGUMENT, L., LETTICE, F. and BHAMRA, T. (1998). Environmentally conscious design: matching industry requirements with academic research. *Design Studies,* 19(1), pp. 63-80.

[2] BAXTER, M. (1995) Product design: Practical methods for the systematic development of new products. London: Chapman & Hall.

[3] 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.

[4] CROSS, N. (2000) Engineering Design Methods: Strategies for product design. 3rd edn. Chichester: John Wiley & Sons.

[5] CROSS, N. (1992) Design Principles and Practice Block 1 An introduction to design. Milton Keynes: Open University Press.

[6] DE VAUS, D. (1996) Surveys in Social Research. fourth edn. London: UCL Press Ltd.

[7] DORISH, P. (2001) Where the Action is: The foundations of embodied interaction. London: MIT Press.

[8] DORST, K. (2006) Understanding Design: 175 Reflections on Being a Designer. Amsterdam: BIS Publishers.

[9] DORTA, T., PÉREZ, E. and LESAGE, A. (2008) The ideation gap: hybrid tools, design flow and practice. *Design Studies,* 29(2), pp. 121-141.

[10] FISH, J. (2004) Cognitive Catalysis: Sketches for a Time-lagged Brain. In: *Design Representation.* London. Springer, pp. 151-184.

[11] GOEL, V. (1995) Sketches of Thought. London: The MIT Press.

[12] GOLDSCHMIDT, G. and PORTER, W, eds. (2004) *Design Representation.* London: Springer-Verlag London Ltd.

[13] GOLDSCHMIDT, G. (1997) Capturing indeterminism: representation in the design problem space. *Design Studies,* 18(4), pp. 441-455.

[14] GOLDSCHMIDT, G. (1992) Serial sketching: visual problem solving in designing. *Cybernetics and Systems,* 23, pp. 191-219.

[15] HALLER, L. and CULLEN, C.D. (2004) Design Secrets: Products 2: 50 Real-life Projects Uncovered. Mass: Rockport.

[16] HESKETT, J. (1980) Industrial Design. London: Thames & Hudson.

[17] 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.

[18] JONSON, B. (2002) Sketching now *The international journal of Art and Design Education,* 21(3), pp. 246-253.

[19] JONSON, B. (2005) Design ideation: the conceptual sketch in the digital age. *Design Studies,* 26(6), pp. 613-624.

[20] LAWSON, B. (2004) What Designers Know. Oxford: Architectural Press.

[21] MCCULLOUGH, M. (1997) Abstracting Craft: The practiced digital hand. London: MIT Press.

[22] MENEZES, A. & LAWSON, B.(2006) How designers perceive sketches.*Design Studies,* 27(5), pp.571-585.

[23] PATRICK, T. (2006) Contributions of designers to improving buildability and constructability. *Design Studies,* 27(4), pp. 457-479.

[24] PEI, E. (1998) Building a Common Ground: The Use of Design Representation Cards for Enhancing Collaboration between Industrial Designers and Engineering Designers. *In proceedings of DRS2008*. Sheffield Hallam University. pp 037/1-037/18.

[25] PIPES, A. (2007) Drawing for Designers. London: Laurance King Publishing.

[26] POWELL, D. (2007) Product Design: the essentials of product design [Design Council online]. Available at <http://www.designcouncil.org.uk/en/About-Design/Design-Disciplines/Product-design/> [Accessed 04.03.09].

[27] PRESS, M. & COOPER, R., 2003. The design Experience. London: Ashgate.

[28] PUGH, S (1990) Total Design. Harlow: Addison-Wesley.

[29] PURCELL, A.T. & 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.

[30] SCHON, D. (1983) The Reflective Practitioner. London: Ashgate.

[31] SLACK, L. (2006) What is Product Design? Mies, Switzerland: RotoVision.

[32] STOLTERMAN, E.E.A. (2008) Designerly Tools, *In Proceedings of DRS2008.* Sheffield Hallam University. pp116/1-116/12

[33] TOVEY, M., PORTER, S. and NEWMAN, R. (2003) Sketching, concept development and automotive design. *Design Studies,* 24(2), pp. 135-153.

[34] TOVEY, M. (1997) Styling and design: intuition and analysis in industrial design. *Design Studies,* 18(1), pp. 5-31.

[35] ULRICH, K. & EPPINGER, E. (2003) Product Design and Development. New York: McGraw-Hill.

[36] VISSER, W. (2006) The Cognitive Artifacts of Designing. New York: Routledge.