Designerly Ways of Knowing and Doing: Design Embodiment and Experiential Design Knowledge

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Abstract

From divergent, conceptual design through to design convergence and specification, the designer employs a variety of tools of design representation (TDRs) in the development and communication of design intentions. This study investigates how the rich context of design activity influences designer attitudes towards and use of TDRs. A sample of designers of varying levels of expertise in the use of TDRs was identified and semi-structured interviews conducted. Qualitative content analysis was then used to analyse the resulting interview data. A coding frame identified emergent themes relating to the designers' knowledge, understanding and use of TDRs in the embodiment and communication of design intentions. These themes were included in the coding frame as data-driven sub-categories. The final coding frame was then applied to the interview data and the coded segments of discourse were analysed to consider the nature of experiential design knowledge as it is exercised in the use of TDRs. The study contributes to an understanding of the designer's perceptions of TDR use as these perceptions are themselves influenced by the context of design practice and the skills and experiences of the designer. Experiential design knowledge exists as part of a rich and complex contextual activity. Any attempt to understand this knowledge must take account for the ways in which it is embedded within the designer's own engagement with and understanding of this rich context.

Keywords

designerly tools; design activity; design knowledge

Introduction

A key requirement of industrial design is the representation, development and communication of the designer's intentions towards the 'yet-to-be' (Nelson and Stolterman, 2012; Cross 2007). In order to effectively frame (Schon 1991) the often ill-defined design problem (Rittel, 1972; Goel & Pirolli 1992; Cross, 2011), the designer generates numerous solution conjectures. It is through the deployment and reflection upon these solutions (Schon op cit) that the designer is able to both explore the design problem and suggest solution ideas (Cross 2000). Within this process of exploration, development and suggestion the designer will employ tools of design representation (TDRs) to communicate, develop and reflect upon design intent (Visser, 2006; Goldschmidt & Porter, 2004). Pei (2009) identifies 32 digital, analog and hybrid TDRs used in contemporary design practice through the taxonomy of sketches, drawings, illustrations, models and prototypes. Within design's rich context these designerly tools play a critical role in supporting an open, explorative, conceptual design activity through to the more constrained, convergent and detailed specification of intent prior to manufacture (Ulrich & Eppinger, 2003).

Figure 1 illustrates a generic model of the industrial design process based upon the divergent/convergent activity of design, as proposed by Cross (2000).

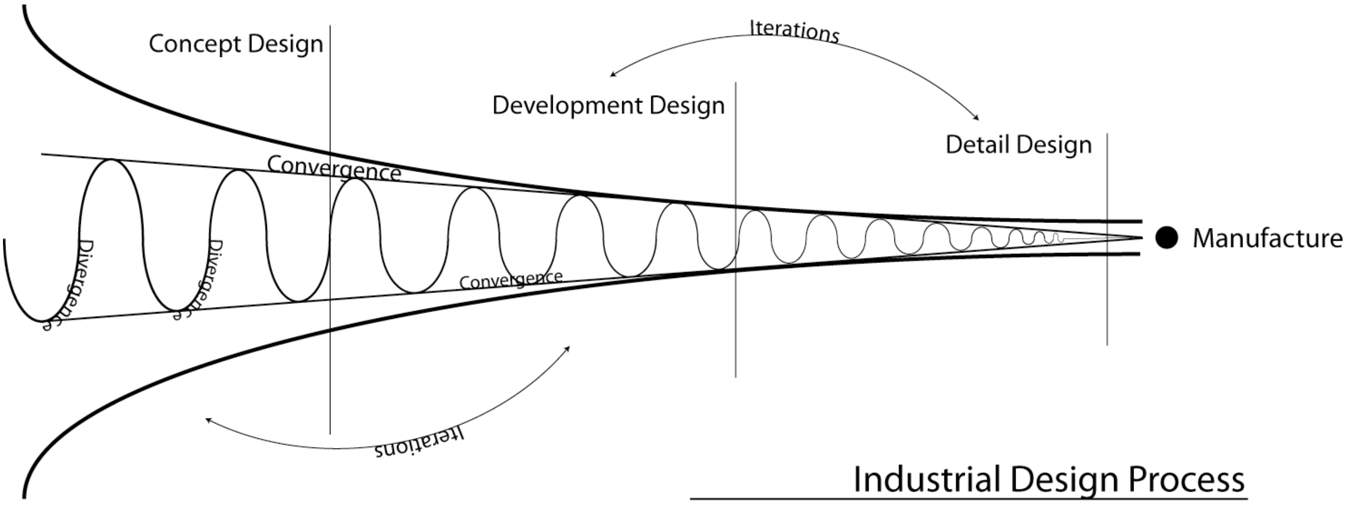

Fig 1. Generic model of industrial design process

Although a simplification of what is in reality a complex and rich activity, Figure 1 illustrates the nature of design as it relates to the often dynamic requirements of the design process. At a conceptual front end in practice design is characterised by a less committed, more exploratory design activity (Ulrich & Eppinger, 2003). Divergence, ambiguity in design embodiment, a required lack of detail and the unspecific character of design representation characteristics associated with conceptual design (ibid). As design moves from concept to development, design intent becomes more fixed, explicit and constrained. Thoughts become clearer and a design direction develops (Fish, 2004).

There exists a growing body of work aimed at understanding the role and affordance of TDRs in the complex and rich context of design practice. This research has often employed methods that simulate the design process to generate data on tool use (Goel, 1995; Purcell & Gero, 1998; Bilda and Demirkan, 2003; Fish, 2004; Jonson, 2005; Menezes, Arquitetura & Lawson, 2006; Dorta, 2007). This results in a focus upon the affordance and constraints of individual design tools rather than the designer's motivations for their approaches to design activity, choice and use of TDRs. This is of course understandable. To study any complex phenomena steps must be taken to simplify and isolate its component parts (Simon 1996). However, a drawback of this approach is that it necessarily simplifies what is in reality a rich and complex design activity (Stolterman, 2008b).

In contrast to these tool-centric studies Stolterman, McAtee and Thandapani (2008a) illustrate how practicing designers actually view and use designerly tools. Through a small sample of designers, Stolterman et al. (2008a) investigated designerly tools as their use relates to the purpose of design practice; the activity required to achieve that purpose and the tool(s) seen as best supporting the design activity. Similarly, this study attempts to balance tool-centric approaches to the study of design tools and their use with a more holistic description how design tool use relates to and is informed by the rich context of real-world design practice.

Research Aim

This investigation aims to go beyond an analysis of individual design tools to explore how designer perceptions of the contextual requirements of design activity inform TDR (Tools of design representation) use. To this end the study aims to address the following research question: How does the rich context of TDR use influence the ways in which designers employ TDRs during design activity?

In addressing this question the study aims to develop a more holistic understanding of the principles and influencing factors that inform the designer's use of TDRs, and so contribute to an understanding of experiential design knowledge.

The human activity of design is complex. In an attempt to map this complexity before moving to investigate its component parts, Activity Theory (AT) was identified as a strategy to underpin the study of design activity. Specifically, AT was used as a means to guide research methods in the design of research instruments (interview) and the theory-driven dimensions of a coding frame used in the coding and analysis of interview data.

Design Activity & Activity Theory

In the most simplistic terms, AT is a framework for the study of activity as a process of interaction with the environment (Baber, 2003; Engeström, Miettinen and Punamäki, 1999; Kuutti, 2001). Engeström (1999) proposes a model of AT that describes a number of co-related principles (Figure 2).

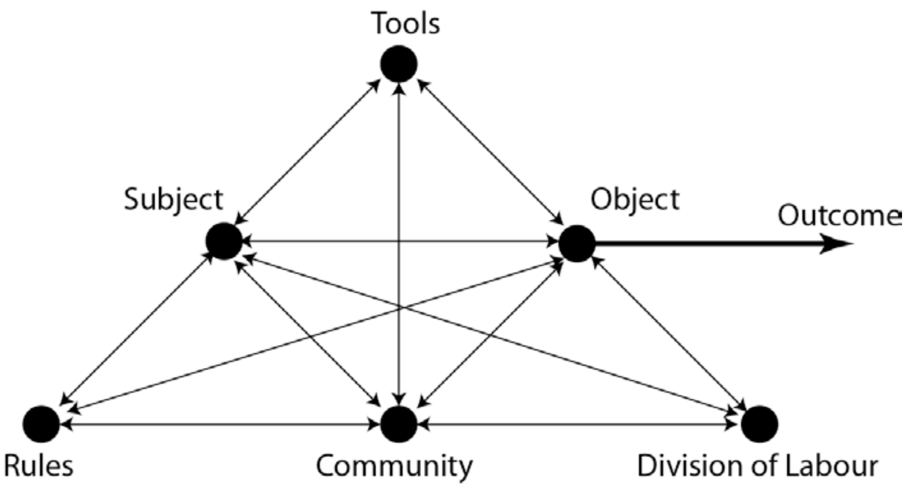

Fig 2. Engestrom's (1999) model of Activity Theory

Engestrom's (ibid) model presents a number of concepts that together inform activity: the context within which the activity takes place (Rules, Community, Division of Labour) the subject performing the activity (Subject), the objectives of the given activity (Object) and the mediating tools (Tools) used to support activity and so achieve the object and final outcome.

Engestrom's (op cit) focus upon environmental context was of particular relevance for this study's aim of exploring the rich context of design practice and its influence upon the ways in which TDRs are employed during design activity.

As a pragmatic example to illustrate Engestrom's (ibid) model, consider the activity of picture hanging. The subject uses a tool (hammer) for the purpose of hammering a nail at the right angle and level to hang the picture (Object), with the goal of hanging the picture at the required height and location (Outcome). However, within this picture-hanging activity contextual rules and conventions also apply (Rules, Community, and Division of Labour). The picture is hung at head-height and centred in relation to adjacent walls; family portraits climb the stairs; images of boats and water are located in bathrooms. A more extreme example of cultural context as influence upon the activity of picture hanging can be seen in the Democratic Peoples' Republic of Korea (DPRK). In the DPRK (North Korea) all houses must by law have two portraits of the North's first communist president Kim Ill Sung, 'the great leader' and his late son Kim Jung Ill, 'The Dear Leader' located prominently in every home, office, factory or school classroom. The portraits are required to be positioned above head height and adjusted at such an angle so that the top of their frames sit off of the wall (Oberdorfer, 2001).

Design activity and the activity of picture hanging are very different in many ways. AT uses the assumption that activity is directed towards a known goal or outcome. As previously discussed, design activity often involves the exploration of ill-defined problems where the outcome or goal state is not and cannot be known (Rittel, 1972). However, a discussion of the strengths and limitations of AT as a means to explore design activity are beyond the scope of this paper. Rather than concerning itself with a validation of AT as a means to explore design activity, our study employs Engestrom's (1999) model, and the principles suggested within it, as a guide for the design of interview questions and subsequent coding of responses. Any limitations of such an approach, although acknowledged, are not further discussed here.

Research Methods

Although the observation, recording and analysis of activity can provide insight into design activity (Cross, Christiaans & Dorst, 1996), these methods are less well suited to research aiming at exploring the individuals thinking and motivations for a given activity as it relates to a real world context. Romer and Pache (2001) argue that observation cannot 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) notes that behaviour cannot be understood without reference to intentionality. Nelson & Stolterman (2012) consider that experiment and observation may not be entirely appropriate to the study of design knowledge as it relates to design activity as principles of observation cannot transcend their own context.

In contrast with observational studies or protocol experiments, social research methods are often used to explore respondent attitudes and reasoning (Miranda, Peters & Harrie, 2007; Robertson & Radcliffe, 2009; Argument & Bhamra, 1998). Because this study aims to investigate motivations and perceptions of TDR use, we employ semi-structured interviews to generate qualitative data which is subsequently subjected to a qualitative content analysis.

Sampling

Interviews where sought from design practitioners at various stages in their careers and the researchers' personal contacts within industry were utilised to identify potential interviewees. Individuals were then contacted to secure interview dates. In choosing the interview sample the authors used two decision criteria. First, interviews were sort from practitioners that described themselves as product and/or industrial designers. Second, interviews were sort from designers working within different contexts, SMEs (Small & Medium sized enterprises), corporate environments as well as less experienced final year design students. Here the intention was to gather data from a broad cross-section of working contexts and levels of expertise, rather than to specify any particular context of practice or level of experience.

The Dreyfus and Dreyfus (1986) model of Stages of Skills Acquisition was deployed to classify the interviewees' levels of design expertise. 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 'Competent'; 4-8 years as 'Proficient'; and 9 years or over as 'Expert'. The attributes of the interview sample are presented in Table 1:

Designer	**Level of Expertise**	**Type of Employment**	**Job Title**	**No. of years experience**
AC01	Proficient	SME	Designer	4
AD02	Expert	SME	Designer	16
CL03	Expert	Corporate	Design Director	19
EG04	Proficient	SME	Snr Designer	7
K05	Expert	Corporate	Design Manager	11
TT06	Proficient	SME	Designer	5
St07	Advanced Beginner	Education	Intern	1
St08	Advanced Beginner	Education	Intern	1
St09	Advanced Beginner	Education	Intern	1

Table 1. Interview Sample

Although the interview sample was relatively modest each interview was conducted over a period of between 45 and 80 minutes. This resulted in 99 pages of transcribed interview data. Responses were then segmented using a thematic criterion, resulting in 1075 segmented commentaries or units of coding. The amount of data generated from the interviews was sufficient to both achieve the requirements of exhaustiveness, through the assignment of each unit of coding to at least one subcategory in the coding frame, and saturation; the ability of the data to account for all dimensions in the frame.

Interview Design

A semi-structured approach to interview was used as its qualitative nature is particularly effective in gathering data based on emotions, experiences and attitudes (Bryman, 2008; Robson, 1993). The interviews employed a set of 9 open questions (Table 2), allowing flexibility in response (Robson, 1993). This approach enabled interviewees to speak widely of their attitudes towards design activity and use of TDRs (Denscombe, 2003).

Interview Questions
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 organization?
Q9: Given the abilities you have suggested, could you say why it is important for a designer to have these abilities?

Table 2. Interview Questions

Question 1 attempted to establish a context for discussing design activity and use of TDRs. Questions 2 to 7 were included to generate discussion on the interviewee’s understanding of the context of TDR use and their approach to design activity. Questions 8 and 9 were designed to facilitate discussion of design skills and knowledge as it relates to the activity of design and the context of TDR use.

Interview Data Coding and Analysis

Qualitative content analysis (QCA) was employed as a method to analyse the raw interview data. QCA was used ahead of other qualitative methods, such as semiotic analysis, because the study aimed to identify and describe concepts and principles within the data. In order to analyse the raw interview responses a part data, part theory-driven coding frame was constructed. The principles illustrated in Engestrom's (1999) model of AT (Figure 2) were used as the 4 dimensions or main categories of the coding frame. Sub-categories were then identified through an initial analysis of the interview data for emergent themes. As themes were identified, sub-categories were formed and added to each of the frame's 4 dimensions. This process continued until no new themes were identified. The final coding frame is illustrated in Figure 3:

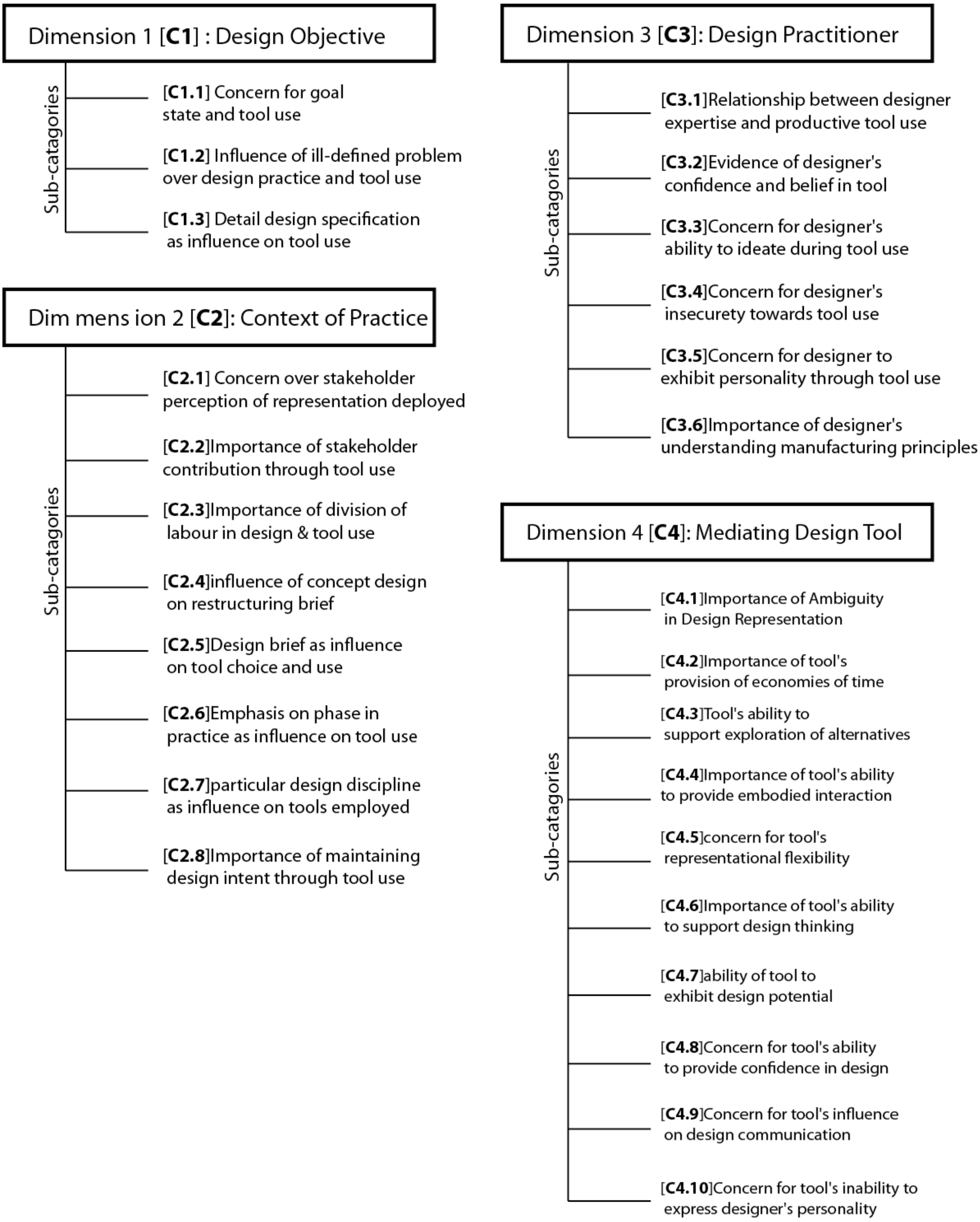

Fig 3. Coding frame

Following the construction of the coding frame the interview transcriptions were segmented using thematic criterion. With the coding frame in mind, the coder segmented interview data into units of coding according to utterances that had a common point of reference. The segmentation of the 9 interview transcripts resulted in 1075 units of coding. A pilot analysis of the coding frame was then performed and the coding frame applied to the first page of each interview transcript. As a result adjustments to sub-categories, their titles and descriptions were made, with some sub-categories being collapsed together. Finally, a main analysis phase applied the revised frame to the 1075 units of coding. After the main analysis phase was complete, in order to check reliability, the frame was again applied to a sample of the segmented units of coding at a separate point in time. The coding from the main analysis and reliability check were then compared for consistency.

Results

The coding frame, the ways in which the interview transcripts were segmented and coded and apparent agreement and difference between interviewees were analysed. The following sections present results in terms of the frame's 4 dimensions. Each section illustrates those sub-categories for each dimension that received an absolute frequency of coding greater than 50. This is followed by a comparison of coding between the three levels of expertise represented by the interview sample (advanced beginner, proficient, expert, Table 1).

Dimension 1 [C1] Design Objective

Dimension 1 [coded as C1] was assigned units of coding that referred to AT's concept of 'Objective': the influence of the objective of an activity upon the activity itself. Three themes were identified within the interview data as referencing design objectives (Figure 4).

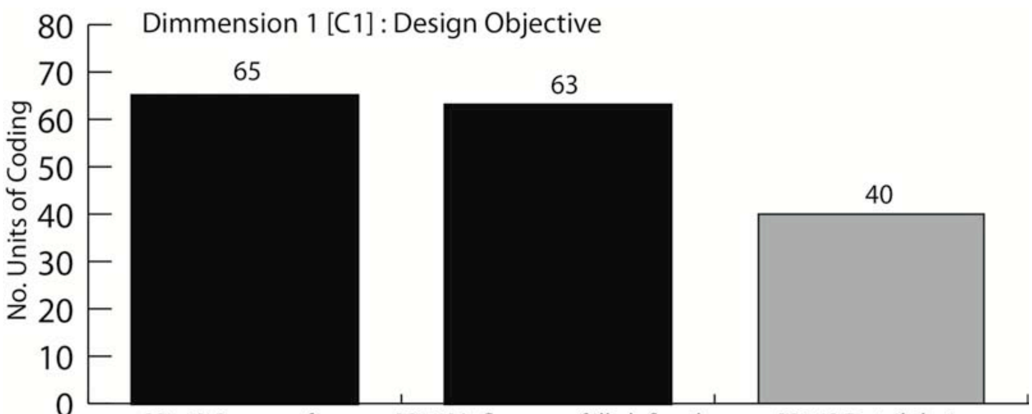

Fig 4. Absolute frequency of coding for 3 sub-categories

Subcategories C1.1 and C1.2 received absolute frequencies greater than 50. C1.1 was assigned to units of coding whenever a designer referenced a goal state as influence upon design activity. Subcategory C1.2 was assigned when designers referenced the design problem as an influence on design activity and TDR use. Tables 3 and 4 illustrate these 2 sub-categories with examples of units of coding assigned to C1.1 and C1.2.

[C1.1] Concern for goal state and tool use	Description
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. (AC 01)	Concern for process of manufacture
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 (AD 02)	Concern for final outcome and costs
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. (EG04)	Concern for budget and costs as influence upon design communication

Table 3. Coding assigned to C1.1

[C1.2] Influence of ill-defined problem over design practice and tool use	Description
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 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. (K05)	Influence of requirement for exploration of ill-defined problem and use of hand sketching and other tools.
so this is where you're coming up with lots of different concepts of vague ideas [indicating concept design]. 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. (St 07)	Influence of requirement for exploration of design problem on design activity and tool use.
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. (EG 04)	Influence of ill-defined design problem upon activity and tool use

Table 4. Coding assigned to C1.2

Although design activity is often described as dealing with ill-defined problems and un-known solutions, sub-category C1.1 (Concern for goal state and tool use) illustrates the ways in which the designer may consider future goal states during practice. For example, in Table 3 AD02 expresses a concern for clarity in terms of deliverables at the start of the design process. An analysis of coding assigned to C1.1 indicates that these concerns often relate to pragmatic considerations, *'suits their budget and their expectations, so there are no surprises'*. This suggests the ways in which designers take account for the final goal of design development, not by envisioning any final goal solution, but rather by framing the design problem within pragmatic constraints. Related to C1.1, sub-category [C1.2] indicated the ways in which the ill-defined design problem results in the designer's concern for exploration. In Table 4 EG04 describes the ways in which the design brief and its criteria influence choice and use of TDRs, '*If the brief is quite open then we'd probably, defiantly sketch'.*

These findings suggest, although the outcome of design activity is often unclear or unknown, the designer is guided by an awareness of an eventual goal state and perceptions of a best or right way to proceed. Within this an Ability to explore seemed an important principle in the designer's conception of an ability to develop ideas and so progress towards design objectives.

Design Objective & Influence of Expertise

In terms of level of expertise and the designer's engagement with design objectives, findings suggest how experience may influence the designer's perceptions of objectives. Figure 5 illustrates the absolute frequency of coding across the 3 subcategories for dimension 1 for each of the 3 levels of expertise represented in the interview sample:

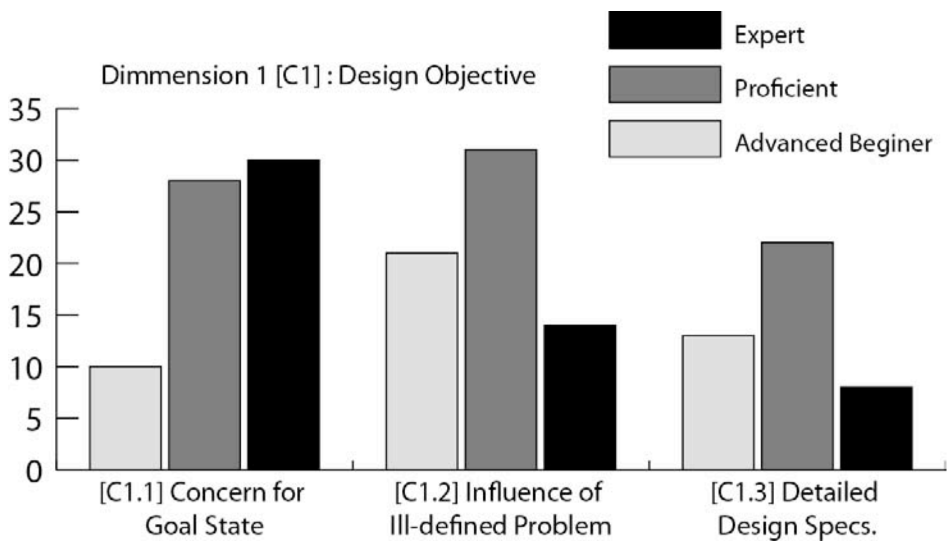

Fig 5. Absolute frequency of coding for each level of expertise

Both the expert and proficient designers recoded higher frequencies of coding than the advanced beginners for the subcategory Concern for Goal State [C1.1]. However, for both Influence of Ill-defined Problem [C1.2] and Detailed Design Specifications [C1.3], the interviewees classified as advanced beginners received a higher frequency of coding than the experts (Figure 5). It may be that more experienced designers tend to consider goals and objectives when engaged in design activity compared to those with less experience of practice. If this is the case this may indicate a relationship between expertise and an awareness and understanding of goals and objectives, and that this understanding then informs the designer's use of TDRs.

Dimension 2 [C2] Context of Practice

The dimension Context of Practice [C2] refers to the designer's consideration of context as influence on design activity and tool use (Figure 6).

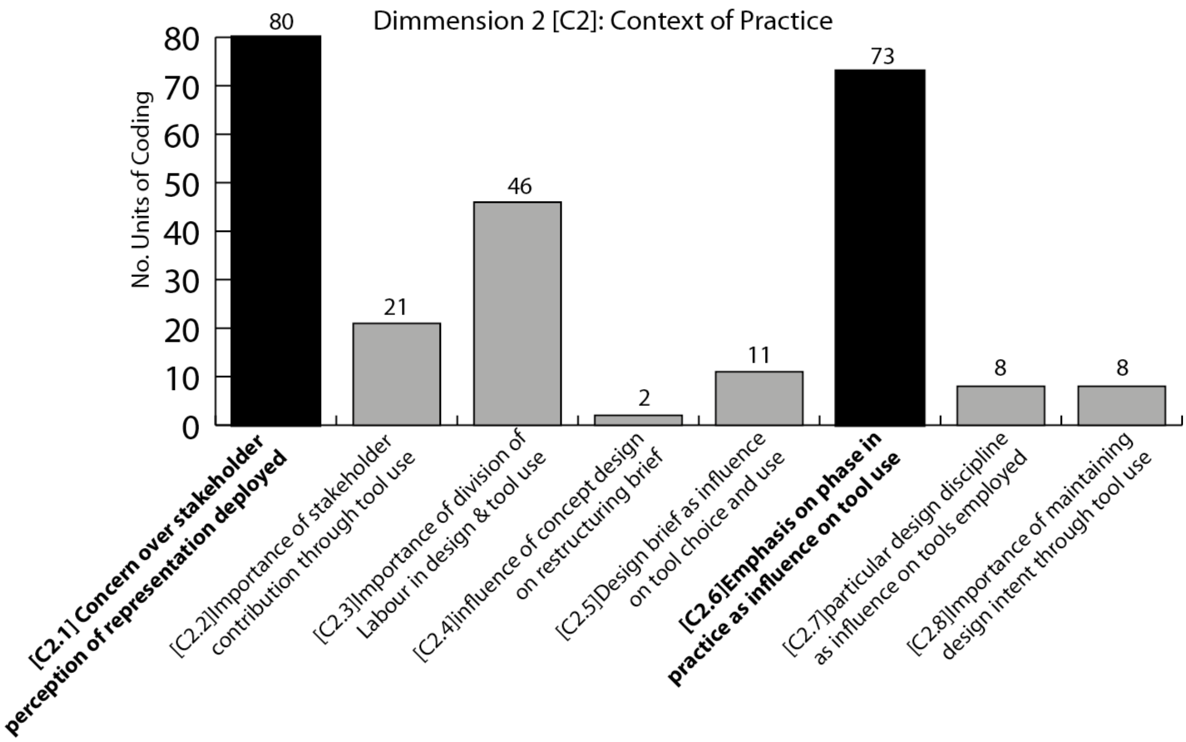

Fig 6. Absolute frequency of coding for 8 sub-categories

Of the 8 sub-categories 2 received absolute frequencies of coding greater than 50 (Figure 6). Representative samples of segmented utterances coded as C2.1 and C2.6 are presented in Tables 5 and 6.

[C2.1] Concern over stakeholder perception of representation deployed	Description
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. (AC 01)	Discussion of the importance of modeling and prototyping for communication of intent to stakeholders
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. (AD02)	Concern over the tool's influence on representation and the resulting communication of ideas to stakeholders
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.' (CL03)	Concern CAD's influence upon the communication of design intentions to stakeholders

Table 5. Coding assigned to C2.1

[C2.6]Emphasis on phase in practice as influence on tool use	**Description**
Usually we try to be pretty quick at this point [concept design], so we don't spend too long on it (EG01)	The character of concept design as influence on the ways tools are used during design activity.
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 (K05)	Stage of development (development design) as influence on the character of design representation.
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. (ST07)	Discussion of stage in practice as influence upon the kinds of representations made.

Table 6. Coding assigned to C2.6

Results indicate the designers' concern for stakeholder perceptions of their own design intentions (C2.1, Table 4) and phase in practice as a reference point for discussing the nature of their design activity (C2.6, Table 5). It appears the kinds of representations of design intent made are dependent upon the designer's concern for and understanding of stakeholder perceptions. AD02 indicates this when commenting that, '*although the two [design representations], you could argue, were equally well or not so well resolved, the fact that they are communicated differently, people's reaction is different.'* AD02 indicates concern for stakeholder perceptions of the TDR used. It appears the designers' perception of the use of TDRs is particularly influenced by how they believe they may communicate design intent to others.

Related to this, the findings indicate the ways in which the designers used phase in practice as a reference point for discussing the nature of their own design activity and the kinds of design representations employed in support of their own practice, *'Usually we try to be pretty quick at this point [concept design], so we don't spend too long on it' (EG01)*. This appears indicative of the designers' perception of a correct way to engage the various phases in design practice and the TDRs best suited to do so.

Context of Practice & Influence of Expertise

With respect to the influence of expertise upon an understanding of contextual influences during TDR use, a number of contrasts between interviewees classified as expert, proficient and advanced beginner were seen (Figure 7).

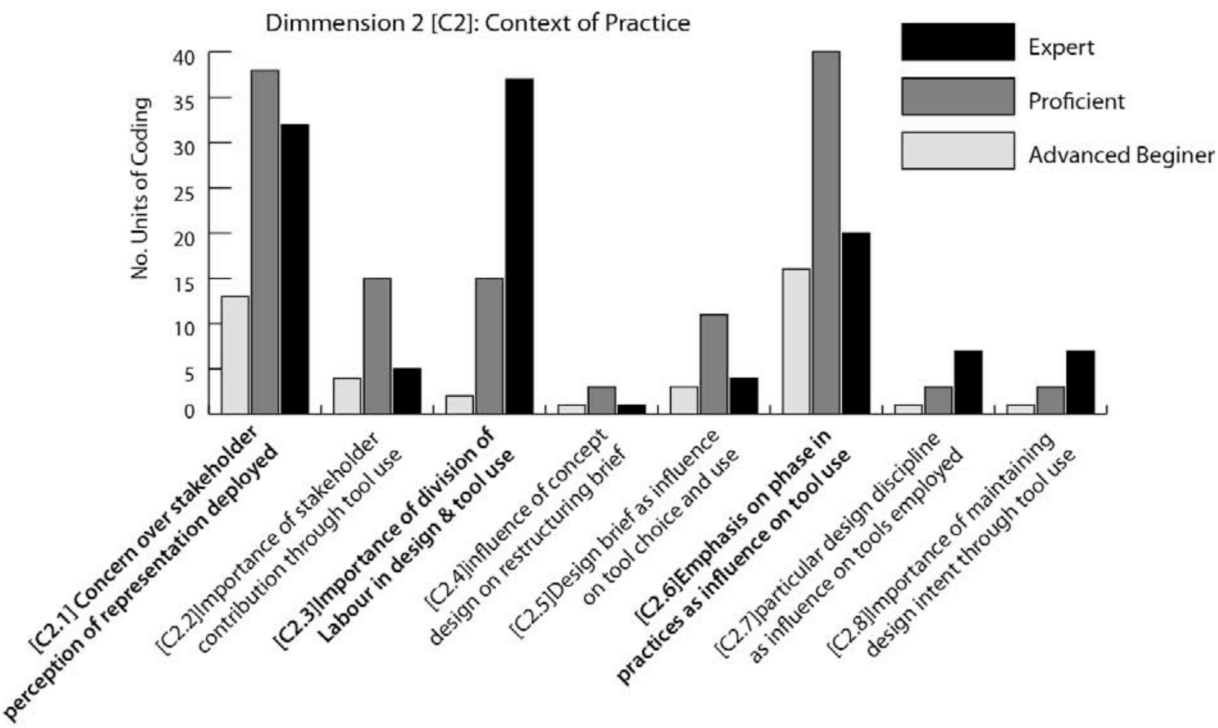

Fig 7. Absolute frequency of coding for each level of expertise

In particular subcategories C2.1, C2.3 and C2.6 showed noticeable differences in the frequency with which each subcategory was used to assign units of coding across the three levels of expertise present within the interview sample. Results suggest designers with more experience of practice may be more inclined to consider stakeholders' perceptions of the design representations employed in the communication of design intent (C2.1, Figure 7). The expert designers, and to a lesser extent the proficient designers may also be inclined to consider division of labour as influential in the use of TDRs during practice (C2.3). It was interesting to note that C2.3 was of particular importance to the experts, who were also directors of their own design consultancies or, in the case of interviewee K05, a design manager at a large corporation. Subcategories C2.6 received higher frequencies of coding with interviewees described as proficient in practice compared to both those interviewees classified as expert and advanced beginners.

It is unclear as to why the expert designers were inclined to discuss phase in practice (C2.6) as an influence upon the use of TDRs. It may be that the advanced beginners have less experience of design in the context of a commercial setting. This may then account for their fewer references to the influence of design context across the coding frame's 2nd dimension (Figure 7). That is, in all 8 subcategories of dimension 2, both experts and proficient designers received higher frequencies of coding than the advanced beginners. It may be that a holistic awareness of context as an influence upon TDR use develops with experience. And thus less experienced designers are not inclined to consider context when deploying TDRs in support of their design activity. In contrast, and with experience, perceptions of context develop along with an awareness of how context may relate to TDR use.

C2.6 (emphasis upon phase in practice as influence upon tool use) saw a higher frequency of coding among the proficient designers only (Figure 7). This could indicate a heightened awareness of, and interest in, stage in practice as it relates to TDR use compare with the experts. If this is the case it may be that designers with middling levels of expertise have stronger perceptions of and interests in TDR use as it relates to the pragmatic requirements of design. This could indicate a relationship between the role and responsibilities of proficient designers and the ways in which responsibility influence perceptions of TDR use during studio practice. That is, those designers classified as proficient are more inclined to consider how use relates to the design process. This may tell us something of the responsibilities of these mid career designers. It could be that a heightened perception of TDR use as it relates to a design process is evidence of the proficient designers' day to day engagement in design activity. This may be in contrast to less experienced advanced beginners, who are yet to develop their experience and with experts who now see their role evolve into more advisory and managerial duties.

The significant differences between frequency of coding for expert and proficient designers for subcategory C2.3 (importance of division of Labour in design and tool use) may indicate the importance experts place on this division. This could again suggest the expert designers' responsibilities in managing the use of TDRs across a number of individuals. That is to say, the experts' role as design manager or director influences their consideration for how, where and by whom TDRs should be used.

Dimension 3 [C3] Design Practitioner

Dimension 3 [C3] was assigned units of coded data related to perceptions of the designer as influence upon the use of TDRs. 6 data driven sub-categories were identified as relating to the dimension (Figure 8).

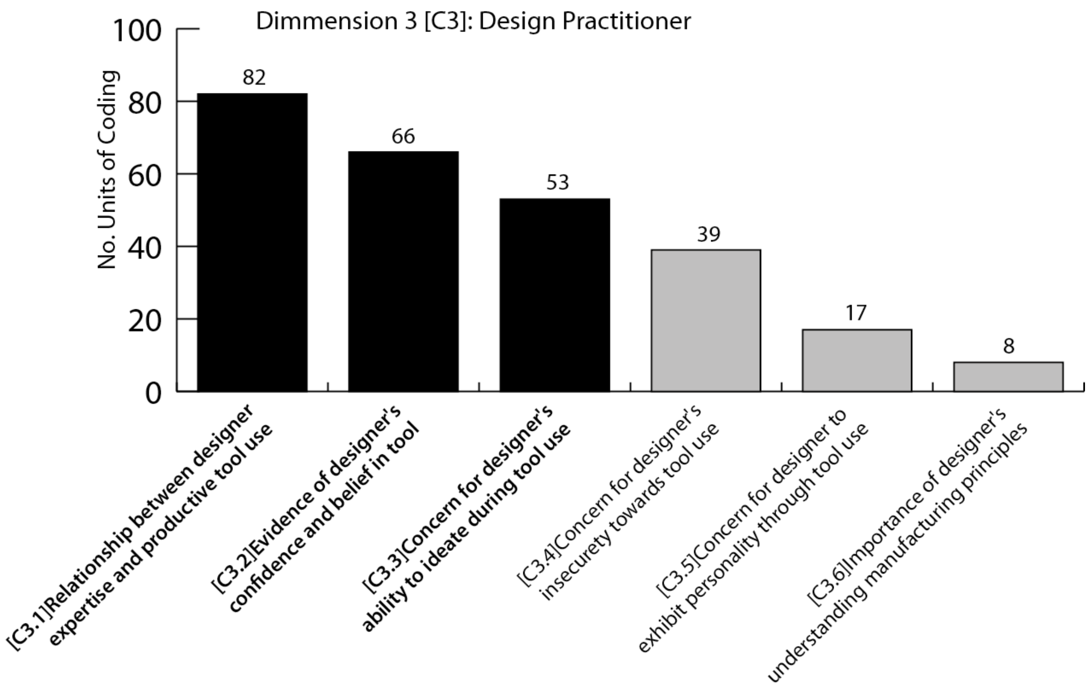

Fig 8. Absolute frequency of coding for 6 sub-categories

Of the 6 sub-categories, 3 received an absolute coding frequency of more than 50 (Figure 8). Tables 7, 8 and 9 provide representative examples from these 3 sub-categories.

[C3.1] Relationship between designer expertise and productive tool use	Description
because we, myself and my college, became very proficient in, in CAD, that became very fast as well (AC01)	Relationship between skilled tool use and efficiency of work and time during design activity.
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 (AD02)	Concern for the unproductive use of design tools by less experienced designers resulting in poor design.
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 (CL03)	Discussion of difference between ability to deploy design tools and ability to design

Table 7. Coding assigned to C3.1

In terms of the design practitioner's influence on design activity and tool use, results indicated the designers' consider design ability as existing prior to or separate from the skilled use of tools. Unites coded as [C3.1] (Relationship between designer expertise and productive tool use) indicated the designers' emphases on design ability as a driver for innovative design and productive use of TDRs. Expertise in design activity appears to be seen as possible only through an ability for good design which then underpins the use of TDRs, *‘And there are too many students that all come out being able to do 3D renders but the design itself is horrible’ (CL03).* Here the interviewee describes a relationship between TDR use and limited design ability. Related to this, findings also indicate the designers’ strong belief in TDR use in support of design activity ([C3.2] Evidence of designer's confidence and belief in tool, Table 8).

[C3.2] Evidence of designer's confidence and belief in tool	Description
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 (EG04)	Emphasises the importance of physical modeling in the representation of design intentions
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. (K05)	Discusses the importance of hand sketching and its ability to support concept design.
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 (St08)	Emphasises his confidence in sketching as a means to support the effective communication of design intentions.

Table 8. Coding assigned to C3.2

Expressions of confidence in a tool’s ability to support a given design activity were found across the sample of designers. The findings indicate the designers hold strong, perhaps deeply rooted and often personal opinions of the TDRs they use and the ways in which they may support design activity. Related to this, results also illustrated the designers’ concern for an ability to explore and ideate during design activity ([C3.3] Concern for designer's ability to ideate during tool use).

[C3.3] Concern for designer's ability to ideate during tool use	Description
It just flowed better [when sketching]. 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 rout, 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 (AC01)	Concern for designer’s ability to explore and ideate while using some design tools
If in the middle of a sketch he has moved onto his next idea because he’s finished with that one. Whereas 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. (CL03)	Evidence of the designer’s concern for design activity and tool use that affords exploration.
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’ (EG04)	Discussion of the importance of divergent design thinking during design activity.

Table 9. Coding assigned to C3.3

The emphasis placed upon a designer's ability to ideate indicated a concern for exploration as a means through which design ideas develop. The findings suggested the importance the designers place upon an ability to engage in design activity that might be described as divergent and explorative, indicating the importance placed upon exploration as a core design competency.

[C3] Design Practitioner & Influence of Expertise

Figure 9 illustrates differences in the frequency of coding along the 3rd dimension of the coding frame between the interviewees' 3 levels of expertise.

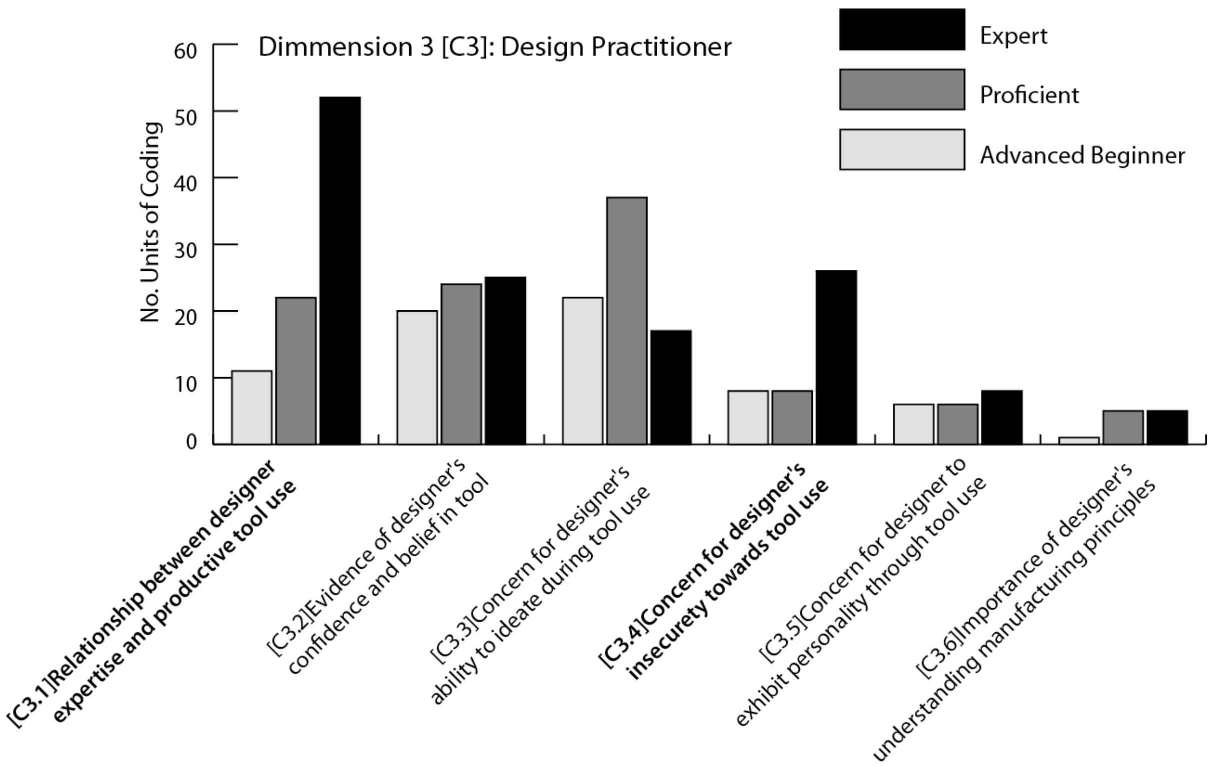

Fig 9. Absolute frequency of coding for each level of expertise

Two subcategories in particular were used more often by one or more of the three levels of expertise present in the interview sample. Those interviewees described as experts were more inclined to discuss TDR use in terms of a relationship between expertise and tool use compared to the advanced beginners or proficient designers (Figure 9, C3.1). This was also true for subcategory C3.4 (concern for designer's insecurities towards tool use). The designers classified as experts had progressed in their careers to positions of authority in relation to human resources and management. As such, they were more inclined to discuss the abilities of less experienced designers and their own requirements in terms of the skills and expertise they look for.

> 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 they're describing that shape to me (Interviewee CL03)

This may indicate a relationship between developing design expertise and perceptions of the role and importance the individual designer plays in their choice and use of TDRs. It may be that very experienced designers (classified as expert within the Dreyfus & Dreyfus model of expertise) are more inclined to consider the influence of the practitioner on the role and use of TDRs. And that their high frequencies of coding is evidence of this tendency. It may be that very experienced designers have a heightened awareness of the role of the practitioner as influence upon TDR use. It could be that these expert designers have responsibility for hiring potential employees. As such they are particularly sensitive to the skills and abilities the designer may bring to their use of TDRs. This indicates the ways in which the designer's particular circumstances, stage in career and levels of expertise all play a part in informing perceptions of TDR use.

Dimension 4 [C4]: Mediating Design Tool

A 4th dimension of the coding frame related to the concept of mediating design tool as influence on TDR use (Engelstrom 1999, Figure 10).

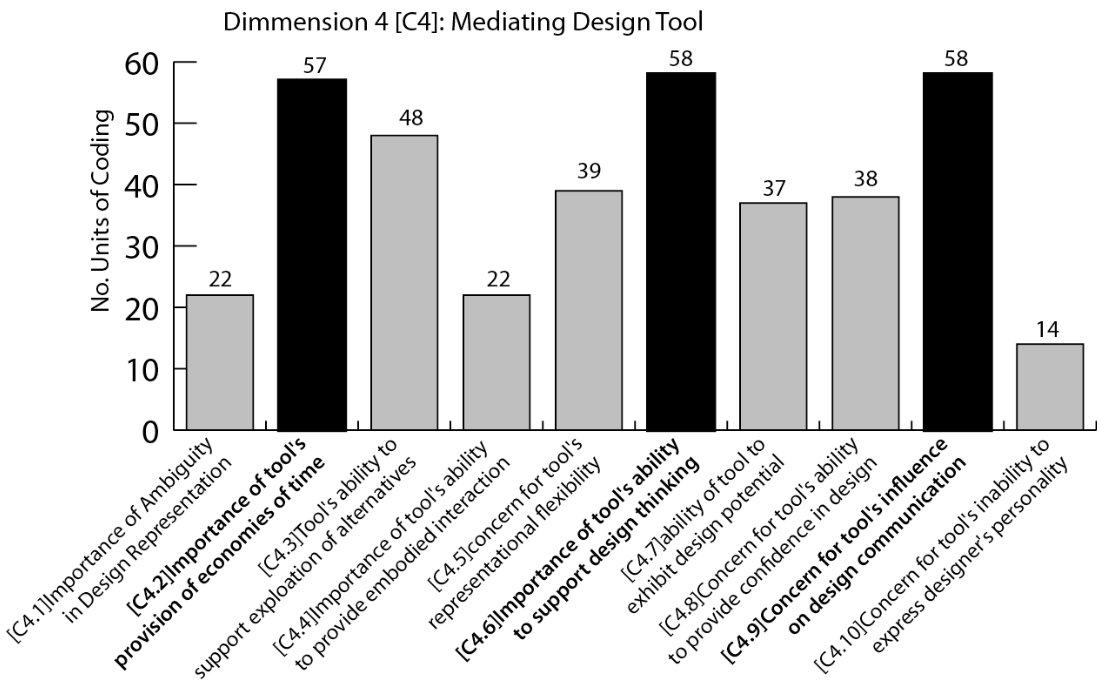

Fig 10. Absolute frequency of coding for 10 sub-categories

Of the 10 sub-categories, 3 showed absolute coding frequencies greater than 50 (Figure 10). Tables 10, 11 and 12 provide an indicative sample of units of coding assigned to the 3 subcategories together with descriptors.

[C4.2] Importance of tool's provision of economies of time	Description
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 (ST08)	Concern over implications of tool use for speed of design development.
No we wouldn't [use 3D printing in support of concept design]. 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 (TT06)	Concern for economy of time and tool use during design activity.
without going into the third dimension, which then can start clocking up more time (AD02)	Discussion of how tool choice and use may result in reduced time economy

Table 10. Coding assigned to C4.2

The results indicated how pragmatic and economic considerations influence the designers' perceptions of design activity and their use of TDRs. ([C4.2] Importance of tool's provision of economies of time). The designers' expression of concern for economies of time related to budget and costs is an indication of how financial considerations exist as a constant pressure upon design activity. The design tool's ability to meet and overcome this pressure was an emergent theme within the designers' discussion of their design practices. Results also suggested the designers' concern for the tool's ability to support the thinking through of design intentions. That is, the designers tended to consider the affordances of design tools in terms of their ability to support such things as the generation of and reflection upon solution ideas, in short, the tool's ability to support a reflective, thoughtful activity of design (Table 11).

[C4.6] Importance of tool's ability to support design thinking	**Description**
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. (AD02)	Discussion of the development of understanding and the tool's role in the facilitation of development.
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. (CL03)	Expression of importance of an understanding of design form through the use of tools of design representation.
Sketching is always; you can always use it to make a record of thoughts and to explore different ideas (EG04	Emphasis on recoding or cataloging thought through tool use.

Table 11. Coding assigned to C4.6

This was particularly evident as the designers discussed their use of sketching, '*but is at that sketch stage. It's understanding what that project, what that new product should be' (AD02)*. Here AD02 discusses the ways in which the act of sketching helps him in the thinking through of design intentions. This would agree with existing work related to the role of sketching as a means to support design thinking (Cross 2007, Fish 2004, Goel 1995).

[C4.9] Concern for tool's influence on design communication	Description
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' (EG04)	Concern over the appropriateness of the design representation in communicating design intent.
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.' (K05)	Concern for the tool's communication of design ideas and stakeholder perceptions.
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.' (TT06)	Discussion of the relationship between the tool's communication of intent and the designer's relationship with stakeholders.

Table 12. Coding assigned to C4.9

Results indicated the designers' concern for the tool's communication of design intent as an influence upon choice and use of TDRs (Table 12). That is, the designers appear to use their own guiding principles concerning the ways in which design ideas must be communicated to stakeholders and how this relates to the affordances and limitations of the TDRs. For example, EG04 discusses the relationship between TDR use and his own perceptions of client expectations, *'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.'* It appears the use of TDRs is understood in terms of perceptions of the ways in which they communicate design intent to various stakeholders. That is, the designer understands tools as having the ability to communicate in various contexts of practice, and that this understanding is synthesised along with knowledge related to client expectations.

[C3] Mediating Design Tool & Influence of Expertise

Figure 11 illustrates frequency of coding for dimension 4 of the coding frame between the 3 levels of expertise present in the interview sample.

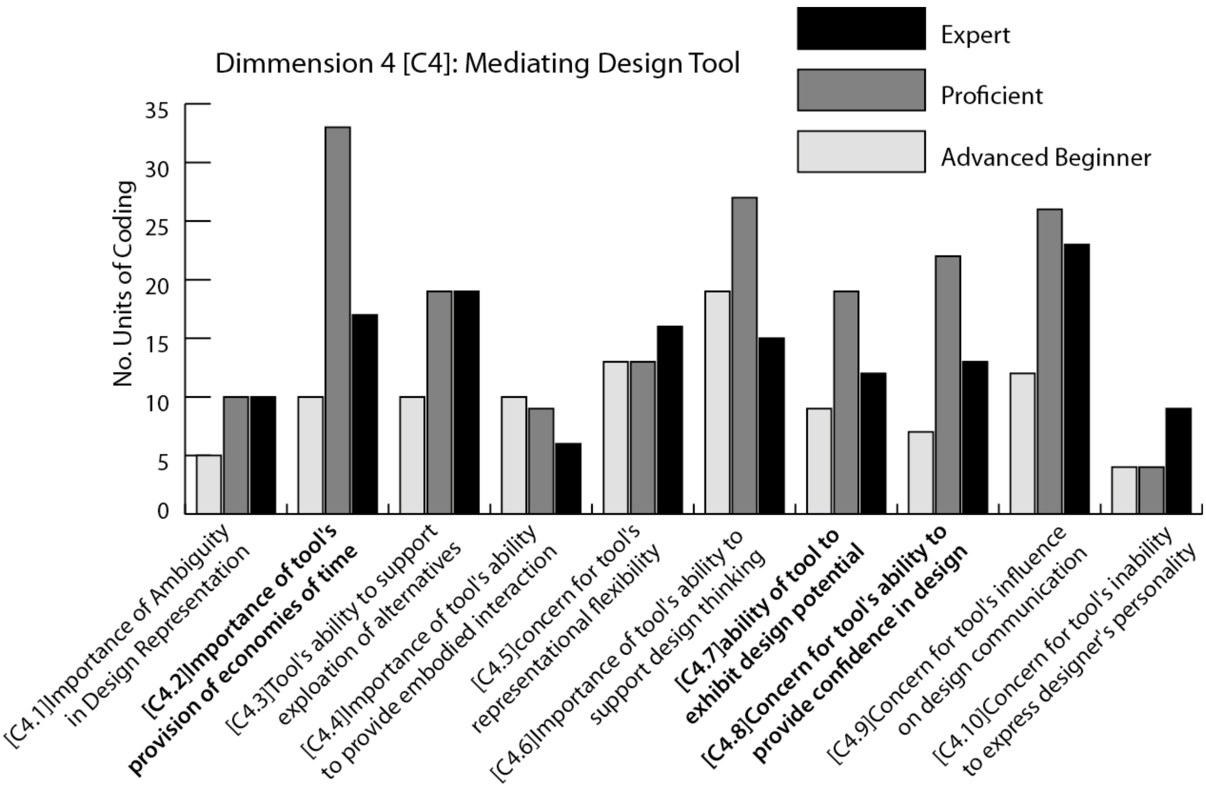

Fig 11. Absolute frequency of coding for each level of expertise

Subcategories C4.2, C4.7 and C4.8 indicated differences in the frequency of coding across the 3 levels of expertise identified in the sample. In terms of consideration for economies of time [C4.2], the proficient designers' responses were coded more often than both the advanced beginners and experts. In the case of the advanced beginners, it may be that economies of time are considered less at an early stage in their career where pressures and responsibilities for the design development related to time and cost are less influential. The expert designers also received a higher frequency of coding for C4.2, but less so than the proficient designers (Figure 11). It may be that the experts are less lightly to have responsibility for use of TDRs in their more managerial roles compared to the proficient designers. As such, this is reflected in their discussion of tools in relation to economies of time.

For subcategory C4.7 (ability of tool to exhibit design potential) the designers classified as proficient registered a higher frequency of coding compared to both the advanced beginners and experts. This may indicate that those interviewees described as proficient in their design expertise are also most concerned with the TDRs ability to exhibit design potential. That is, there is a relationship between this level of expertise and perceptions of TDR use in terms of their ability to communicate design intent.

Indeed, across all 10 subcategories of the coding frame's 4th dimension seven of the ten saw the greatest or equally greatest frequency of coding for those designers classified as proficient in their level of expertise (Figure 11). It may be that those designers at a mid stage in their career are more able to articulate their relationship to TDRs and the ways in which they are employed in support of practice. These results indicate the TDRs role and influence on design activity is foremost in the concerns of a particular level of experts. It may be that proficient designers are more inclined to reflect upon the TDRs they use compared to novice or more expert design practitioners. This tendency could be the result of regular engagement with TDRs as part of their professional studio practice. This is in contrast to both advanced beginners, who lack experience, and experts, who are less lightly to make regular use of TDR due to directorial responsibilities. If this is the case, it appears expertise and critical use of TDRs is related, but that the nature of this relationship is also dependent upon the designer's role and responsibilities within their work context.

Discussion

This study was undertaken to investigate the role and influence context has upon the designer's approaches to design activity, TDR (Tools of Design Representation) choice and use. Results support the notion of design as a rich and complex activity as proposed by Stolterman (2008b). In order to develop a more holistic understanding of the relevance and importance TDRs play in supporting design activity, it is necessary to investigate how TDR use is influenced by this rich context. The results presented in this study make a number of important contributions to an understanding of the interface between the designer's perception of context, their design activity and TDR use.

Although the designers expressed concern for the importance of an understanding of and engagement with ill-defined design problems (Rittel 1972), results also indicate the designers' use of goal states as reference points for TDR use during design activity. Results suggest these goal states are not related to the designers' perception of what the final design solution may be, rather they relate to the designers' understanding of a correct way, to communicate design intent. These guiding principles often appeared to relate to the rich context of tool use (stakeholder requirements, importance of exploration, phase in design development), rather than the inherent properties of the TDRs themselves.

Results have also indicated the designers' concern for stakeholder perceptions of the design representations employed. Findings suggest designers relate TDR choice and use to the ways in which design intentions are communicated and the influence this may have upon stakeholder perceptions of design intent. The designers appear to perceive the affordances of TDRs through the tool's ability to meet a requirement to communicate ideas to stakeholders in a particular style, fidelity or level of abstraction. Related to this, results also suggest the importance of the designers' perceptions of phase in practice as an influence upon the kinds of design activity undertaken and TDRs used. Here results indicated the designers' awareness of design as a process of progressive development. The kinds of design activity undertaken and the ways in which TDRs may be used is dependent upon the designers' perceptions of the requirements of a given phase in design development. However, the designers' understanding of what constituted correct TDR use at a given stage in practice differed between the three levels of design expertise represented in the sample: advanced beginner, proficient and expert designers.

Perceptions of TDRs and the context of their use appear to relate to the designer's level of expertise in a number of ways. First, the expert designers were more inclined to consider goal states and objectives in their choice and use of TDRs. That is, the more experienced designers where better able to critically discuss the rational for TDR use in terms of goals and objectives compared to designers with less experience. These goal states often included discussion of client expectations and their influence upon the use of TDRs along with pragmatic issues of cost and time related to design and manufacture. This heightened awareness of context appears to contradict the notion of a more experiential, unconscious understanding of design practice (Lawson and Dorst, 2009). The experts and proficient designers were both clear and articulate about the influence of context, its affordances and constraints. For example, designers classified as proficient and expert (Dreyfus and Dreyfus 1986) were more inclined to discuss stakeholder influence on their use of TDRs compared to the advanced beginners. This suggests a relationship between expertise and TDR use.

Moreover, in terms of the concept of context as influence on use (Engeström 1999), division of labour was most often discussed by the expert designers compared to both advanced beginners and those described as proficient. This may indicate the ways in which the role and responsibilities of individuals influences their perceptions of TDR use. As design directors and managers, the experts concern themselves with where and by whom TDRs are used within studio practice, rather than a more situated, pragmatic use of TDRs .

Results indicate the more experienced designers, particularly those at a skill level of proficient, understand the use and effectiveness of TDRs in terms of their ability to provide economies of time and an ability to communicate design intentions in a way that they perceive as correct. Here the results indicate a relationship between expertise and a more critical use of design tools. This agrees with Stolterman et al's (2008) notion of a tool-first vs. activity-first approach to TDR choice and use (see also Heidegger 1962). It appears the more experienced designers consider the affordances of TDRs in terms of the requirements of a given stage in design development. In contrast, designers with less experience are less inclined to consider the characteristics of TDRs as they relate to their context of use.

The findings indicate some of the specific concerns and perceptions design practitioners have in terms of context of TDR use, influence of the tool user, the TDR's role and perceived effectiveness and some of the ways in which TDR use is influenced by perceptions of objectives and goal states. An analysis of differences between designers of differing levels of expertise also provided an indication of the relationship between expertise and perceptions of TDR choice and use. In particular, results indicate perceptions of and critical engagement with TDRs is not only dependent upon level of expertise, but also the responsibilities individual designers have in their day to day practice.

Conclusion

Design activity and TDR (tools of design representation) use is often investigated through methods which focus upon the use of tools during simplified design tasks (Goel 1995, Cross, Christiaans and Dorst 1996, Alcaide-Marzal et al 2013). These studies have greatly contributed to our understanding of the use and effectiveness of TDRs and the nature of design activity. However, the methods employed in these studies do not well account for the richness and complexity of design activity (Stolterman 2008b). This study provides evidence for the importance of context as it informs the designer's perceptions of design activity and the role TDRs play within it.

In particular, findings indicate the designers do not perceive design tools outside of this context, rather they understand their use of tools only as use relates to the competing requirements of the design activity. Designers understand the effectiveness of a tool insofar as it is employed within a rich and complex context of use. This study has started to explore and make explicit how concern for context informs the designer's notion of and orientation towards the principles by which they evaluate effective TDR use. Rather than being centred upon the tools themselves, the designer's guiding principles appear to be informed and developed through perceptions of how TDR use relates to the rich, contextual requirements of design practice: stakeholder requirements, pragmatic concerns over economies of cost and time, phase in design development, the nature of design problems, idiosyncratic belief in and use of design tools. This is in contrast with less experienced designers who indicate limited critical engagement with TDR use and its rich context.

With a greater focus on the rich context of design activity and the ways that context is perceived and engaged by designers of differing levels of experience and responsibilities, we will be better placed to develop strategies to effectively support the use of TDRs in design. These findings have implications for design pedagogy in developing curricula for the teaching of tool use that fosters understanding of the rich context of use as it relates to and informs the activity of design. Future research is now needed to further develop understanding of the role this rich context plays in design activity, TDR use and the acquisition of experiential design knowledge.

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