Understanding the Complexities of Design Representation

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Abstract

Design practice is characterised by the use of design representation as the embodiment of design intent. From the ubiquitous hand-sketch to high fidelity prototypes, the designer employs representation as a means to externalise, reflect upon, communicate and develop intentions towards solution ideas. As a result of their importance, efforts have been made to identify, define and classify the attributes of the various design representations often used in practice. In this study qualitative content analysis is used to analyse the complexity of design representations identified within 50 industrial design case-studies. An existing quantitative complexity scale was used as a means to identify and classify the complexity of design representation present within the 50 case-studies. Results indicate limitations for the validity and reliability of objective, quantifiable approaches to the analysis of complexity within design representation. Instead, findings provide further evidence to indicate the central roles subjectivity and interpretation play in the construction of design representation as a critical component of design practice as a process of reflection-in/on-action.

Keywords: Design Representation, Design Practice, Reflection-in-Action

1 Design Representation

From the various and widely used sketch to high fidelity, pre-production prototypes design representation is employed as an essential tool to support the practice of design [1, 2]. Designers use design representation for a variety of purposes, from the quickly drawn thinking sketch to persuasive renderings and digital CAD models [3-6]. In this way, design representation is employed both as a means to support the designer's thinking and reflection in action [7] and to communication design intent to other stakeholders [8, 9]. Considering their various and critical role in support of design practice, studying design representation provides opportunities to develop understanding of the nature of design activity and the kinds of knowing and thinking it entails [6].

For example, Tovey et al. [10] studies the characteristics of CAD (Computer Aided Design) representation and its influence upon practice by comparing the use of CAD and traditional drawings in automotive design. Pei et al. [11] has developed a taxonomic classification of design representation in an attempt to support collaboration between industrial and engineering designers during new product development. An extension to Pei et al. (ibid) taxonomy has been proposed by Kim et al. [12], who indicate its shortcomings in the classification of conceptual design representation. In a further example, Cross [13] presents research to develop understanding of the nature of design problems through an investigation which focuses on the analyses of sketching and its role in design practice. Through the development of a notation systems which focus on transformation [14], Do et al. [15] attempts to interpret the designers' thinking as part of an investigation focused upon design drawings. In this way Do et al's (ibid) study aims to understand the relationship between representation through drawing and its association to design practice. In a seminal work Goel (ibid) explores representation through sketching to suggested important insights into the role sketching plays during conceptual design due to its ambiguous nature, semantic density and ability to provide opportunities for transformations between and among design ideas.

As these previous works attest, the study of design representation is a fertile ground with the potential to provide insights into design practice and the kinds of designerly ways of knowing and thinking it requires [1, 6]. As such complexity within design representation has seen attention in its potential to provide a means of identification and classification. That is, design representation may be systematically and objectively identified and classified through a quantitative analysis of its complexity. For example, McGown et al. [16] suggest a quantification of the levels of complexity present within design representation as sketches is required to, 'appreciate the pattern of information flow in the conceptual sketching activity.' McGown et al. (ibid) present a 5 level complexity scale (see also Rodgers et al. [17]) to measure the complexity of information communicated within representation (Figure 1).

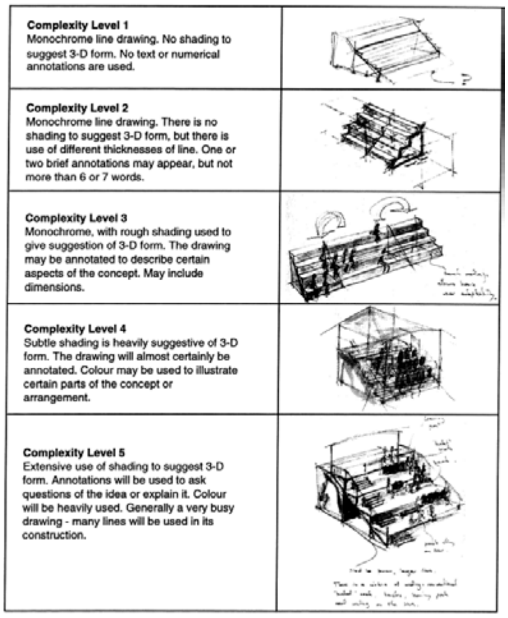

Figure 1 McGown et al. (1998) Levels of Complexity Scale

The scale has subsequently seen use as a means to measure the quantity of information present within design representations [18]; to support an analysis of the content of automotive sketches [19]; and to explicate the complexity of designers' sketches in a study that explored the relationship between complexity in design representation and the number of sketches produced [20].

McGown et al's (op cit) original complexity scale (Figure 1) has provided opportunities to qualitatively assess the information present within design representation. Much existing work related to investigations of and into design representation has also focused upon understanding their use and significance through the analysis of the characteristics of individual instances of representation. The taxonomy developed by Pei et al. [5] describes design representations in terms of the various roles they play as means of communication between industrial and engineering designers. Pei et al's. (ibid) systematic classification provides an indication of the nature of design activity as various design representations are employed, from the ambiguity of a thinking sketch to the high fidelity of a pre-production prototype. The study is indicative of the kinds of information exchanged during each stage in the design process, form divergent, conceptual exploration to convergent specification during detail design. Similar to Pei et al (op cit), Alisantoso et al's [21] description and classification of design modeling methods through clustering suggests a set of guidelines to support practitioners in their choice of appropriate models. In research by Schenk [22] an original taxonomy of design drawings based on their use is presented. The study proposes the use of the taxonomy which characterises, classifies and analyses drawings will help less experienced designers understanding the nature of design drawing. In contrast, Gershenson and Stauffer [23] develop a taxonomy to deal with the design requirements of product design in a more effective way. Their system of classification aims to contribute to the product design process through gathering and managing design requirements which are then deployed in defining product specifications.

Existing research employing taxonomy as a means to identify, describe and classify design representation indicates the advantages of classification. Through classification, hierarchy and relationships among taxons, dimensions or categories may be identified with the potential to develop a richer, more holistic understanding of design representation, its role and use.

However, this study provides evidence to suggest the limitations of an analysis of design representation through complexity as a means of classification. Specifically, the study suggests that, although the scale provides opportunities to define complexity within design representation, the subjectivity inherent in the qualitative application of the scale make uncertain its validity, as a means to describe complexity, and reliability, in classifying complexity. As such we speculate that the measurement of complexity through the quantification of features and elements as a means to describe and taxonomize design representation is limited by the subjectivity required in the application of any such scale or taxonomy. Moreover, we suggest the limitations of the quantitative, objective approach provides evidence to indicate the wider limitations of rational, classical sciences models of design practice; or a science of design [24]. In contrast we speculate that the limitations of the scale's application provide further evidence to support a constructionist view of human perception and thought during design activity. That is, the complexities present within design representation are experienced, defined and assessed by the designer's own reflections upon them.

Rather than complexity existing, a prior, within a design representation, to then be measured and explicated by quantitative means, the extent of complexity is critically determined by the designer's own reflection upon representation. As such, understanding complexity, or any other principle or phenomena, within design representation, and so extending our knowledge of design practice, requires an exploration of the skills and experiential knowledge present in the construction of and reflection upon design representation [1, 3].

2 Aims

The work presented here is part of a larger study aimed at contributing to an understanding of the role and significance design representation plays in designerly thought and action [12, 25]. Specifically, the study aims to contribute to existing attempts to classify design representation as a means to consider their role and significance for design practice. With these aims in mind the wider study addresses the following research questions:

1. How effective are methods of taxonomic classification in the identification, description and categorisation of design representation?

2. What can an analysis of the effectiveness of taxonomic classification tell us about the nature of design representation and the kinds of thinking and action it supports?

The reflection upon and communication of design intentions, through design representation, appears to be critical to the kinds of thinking and actions performed during design practice [1, 6, 26, 27]. In addressing the research questions above the authors seek to contribute to a growing body of work which aims to understand designerly ways of thinking, knowing and acting through the investigation of design representations, their significance, role and use.

Contributing to this wider aim and scope, the paper presents results of an analysis of complexity within various design representations using an existing complexity scale.

3 Methods

A qualitative content analysis was conducted in an attempt to measure and analyse levels of complexity within the various design representations presented within 50 case-studies of design practice published in Bjornlund et al., [28] and Haller and Cullen's [29]. The 50 case studies present and describe the use of design representation through images of sketching, visuals, drawings and prototypes of varying degrees of fidelity taken from live design projects. These 50 cases constituted the study's units of analysis.

In a previous study the same 50 units of analysis were used to define and classify the attributes of design representations [12]. As such, the instances of design representation were previously segmented using thematic criterion. That is, images of design representations and their associated captions were segmented into units of coding according to the different attributes of the representations presented in the case-studies. In order to reduce the likelihood of subjectivity in the segmentation of the design representations, a sample of representation (10 case-studies) were segmented into units of coding by 2 coders individually. Any differences in segmentation were then discussed. This process resulted in 419 segmented representations across the 50 case-studies. These 419 constituted a previous study's units of coding (Kim et al. ibid). For the current study, The same units were revisited by 2 coders in order to assess their segmentation. As a result the 419 units were reduced to 362. Segmented examples of design representation were excluded where it was found to be unclear if the image was in fact a photograph of the final product, rather than a high fidelity prototype for example.

In order to access the level of complexity present within each of the 362 segmented units of coding the levels of complexity scale, first developed by Mcgown et al. [16] and Rodgers et al. [17], and slightly adapted by first Tovey et al. [19] and later by Alcaide-Marzal et al. [18] was used as the bases for the categories or 5 dimensions of a coding frame (Figure 1).

Each of the 362 units of coding was assigned to the 5 categorise by two coders at separate times. Both coders received the same description of the aims of the study: to assess the complexity inherent in various design representations through the application of the 5 level complexity scale. Both coders were research assistances within the same research group at the same institution. Both had equivalent education and experience of design and the use of design representations. In terms of their level of expertise, both fell into the category of 'Advanced Beginner' as defined by the Dreyfus and Dreyfus [30] model of skills acquisition.

Coding proceeded from case 1 to case 50 until all 362 units of coding had been assigned to 1 of the 5 dimensions of the coding frame. The absolute frequencies of coding along the 5 complexity dimensions were then compared to assess inter-coder reliability. That is, coder 1's coding performance was compared with coder 2's to assess the validity of the complexity levels (their ability to describe complexity in design representation) and the reliability of the coding frame (its ability to classify design complexity).

The comparison highlighted the inadequacies of the coding frame to both describe complexity in design representation and to classify it. From these results we hypothesis that the extent of complexity is critically determined by the designer's own subjective reflection upon representation. And for this reason, a description of complexity through an objective, quantification of complexity within representations is limited by its inability to account for the designer's own subjective interpretation of complexity through reflection-in-action, as first described by Schon (1996).

3 Results

Table 1 illustrates frequencies of agreement between 2 coders as 362 units of coding were assigned to the 5 dimensions of the complexity coding frame (n=362). Frequencies are shown as absolute (Frequency f), proportionate (Proportionate f) and as a percentage (% f).

Complexity Agreement	Freque ncy (f)	Proportion f	% f
Agreement	159	.439	43.9%
Disagreement, 1 Level of complexity	142	.393	39.3%
Disagreement, not coded & coded	37	.102	10.2%
Disagreement, 2 levels of Complexity	24	.066	6.6%
	n = 362	Sum = 1.00	Sum = 100

Table 1 Frequencies of agreement between 2 coders

As table one illustrates the absolute frequency of agreement between coders was 159; a percentage frequency (% f) of 43.9. Disagreement of 1 level of complexity between coders was 142 or 39.3% (for example, coder 1 coding at complexity level 1 compared to coder 2 coding the same unit at level 2). Units of coding coded by one coder (along any of the 5 complexity dimensions of the frame), but not coded by the other coder, were identified at a frequency of 37 or 10.2%. Finally, disagreement in the assignment of units of coding by 2 levels of complexity between coders were identified at a frequency of 24 or percentage frequency of 6.6%. As Figure 2 further illustrates, these results indicate limitations within the complexity coding frame in terms of its validity as a means to identify complexity and reliability in its ability to classify complexity along the frame's 5 dimensions.

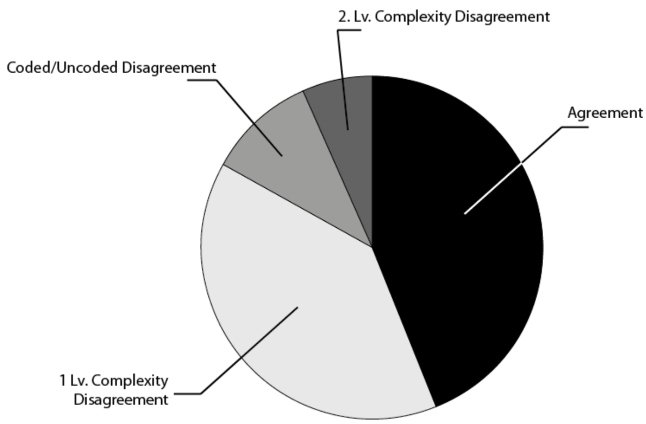

Figure 2 Frequencies of agreement between 2 coders

In terms of inter-coder agreement, results show a percentage frequency of 43.9% (% f) or a frequency of 159 instances of units of coding assigned to the same dimension of the coding frame. However, the frequency with which disagreement in the assignment of units occurred also provides evidence to suggest the level of interpretation required in the assignment of units. This provides evidence to suggest that the explication and classification of complexity within design representation through objective quantification of the characteristics of complexity within instances of representation is unstable. That is, assessing complexity within design representation using existing complexity scales requires a level of subjective judgment to make the scale unsuited to the purpose. Table 2 illustrates the frequency distribution of disagreement by 1 level of complexity across the 5 complexity dimensions of the coding frame.

Disagreement, 1 Level of Complexity	Frequency (f)	Proportionate (Prop f)	% f
Complexity level 1 to 2	24	0.169	16.9%
Complexity level 2 to 3	46	0.324	32.4%
Complexity level 3 to 4	31	0.218	21.8%
Complexity level 4 to 5	41	0.289	28.9%
	N = 142	Sum=1.0	Sum=100

Table 2 frequency distribution of disagreement by 1 level complexity

Of the 142 instances of disagreement the greatest frequency of disagreement was found where one coder assigned a unit of coding as complexity level 2, while the other assigned the same unit to complexity level 3 (% f = 32.4%), closely followed by Levels 4 and 5 (% f = 28.9), levels 3 and 4 (% f=21.8) and 1 and 2 (%f=16.9). These findings provide evidence to suggest parts of the coding frame may be less valid and reliable in describing and classifying complexity. That is, complexity classified from levels 2 to 3 and 4 to 5 was more lightly to result in disagreement compared to levels 1 to 2 and 3 to 4. This would agree with previous studies that indicate the difficulties in objectively defining and classifying representations, particularly those often used during conceptual design [12].

Discussion & Conclusions

How and to what extent a definition and classification of complexity within design representation of different levels of fidelity is dependent upon subjective interpretation is still unclear. However, these results provide evidence to suggest issues with the levels of complexity in their ability to objectively quantify the complexity of design representation. As such, results provide evidence to indicate the limitations of quantitative, objective methods in defining and classifying design representation. We speculate that, due to the subjective interpretation inherent in the construction and use of representations as tools for design, any attempt at identification and classification must account for how representations are actually perceived by those that may use them. As such we position these findings as further evidence to describe design practice as an experienced and reflective activity; highly sensitive to the skills, knowledge and experiences individual designers bring to the externalisation, development and communication of design intent.

There is little doubt design representation plays a critical role in the practice of design. Further studies are now required to understanding and define representation. These studies must however investigate representation as it is experienced as a means to provide further insights into the human activity of design.

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