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IDENTIFYING REQUIREMENTS FOR RENDERING IN CONCEPTUAL DESIGN

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Abstract

This paper presents a study on different aspects of rendering in conceptual design through a questionnaire. The study has provided insights into the aspects of rendering that need future development/attention in conceptual design. The results show that rendering, especially non-photo realistic rendering, is used in conceptual design for better visualisation and communication, using fairly vague to very precise concepts. Also, absence of a sketchy look, lack of differentiation between essential and non-essential information, absence of exploring alternate solutions and absence of inviting assumptions are found to be the most dissatisfying factors in current systems. With respect to establishing greater interaction between designers and current systems, the findings were validated by mapping the identified requirements with rendering techniques, and carrying out an investigation with design practitioners.

Keywords: rendering, visualisation, vague geometry, interacting cognitive system

1 Introduction

During the design process, a designer's geometric design can gradually evolve from its original vague geometric concept towards a more detailed design and eventually to the specification of the final product [1]. These concepts, even in their vague state, are often transferred into or directly developed in existing Computer Aided Design (CAD) systems in order to visualise and compare them. This process involves the mapping of the designer's mental model onto the computer model. Mental models are the internal representations of the designer's ideas, concepts or intentions [2]. The mental model is often vague, abstract and incomplete, whilst the process of generating geometries in traditional CAD systems is specific and requires precise geometric representations. Consequently, there is significant loss of information during the mapping. That is, there exists a mismatch between the designer's mental model and computer model. Thus, the original intent and vague information in the design concepts are often lost, which is a hindrance to true symbiosis. Therefore a different principle of communication needs to be explored that exploits a compromise between retaining vagueness and providing real time communication between human designers and computers.

The work described in this paper is directed at supporting interactive human-computer symbiosis in conceptual design. Human-computer symbiosis is an expected development in cooperative interaction between humans and computers [3]. The overall aim of the research is to develop a symbiotic interaction between human designers and computers that supports the designer's natural working method and promotes the maintenance of flexibility (least commitment) using *vague rendering* by:

– computationally supporting incomplete and vague concepts,

- facilitating computer models that are closer to mental models of design concepts; in short the computer model should more closely reflect the mental model, and
- minimising the loss of information during mapping of design concepts onto the computer model.

Vague rendering is the graphical presentation of vagueness inherent in a concept representation. For symbiotic interaction between human designers and computers, it is necessary to make use of different principles of communication and control [3], such as different rendering approaches to support geometric modelling. Thereby, the research problem is: what are the most appropriate rendering techniques to present a given representation? Hence two issues are addressed: why and how to develop interactive human-computer symbiosis for real time communication between human designers and computers. The former (why) implies a conceptual understanding of requirements for the graphical presentation of a representation effectively. The presentation requirements were derived from:

- a study of the different aspects of rendering in conceptual design, and
- the model of Interacting Cognitive System (ICS) [4], which describes how visual information is processed and understood by humans.

The latter (how) specifies the presentation methods of a representation. This can be done by:

- mapping the identified presentation requirements with existing and new rendering techniques.

The paper concentrates on the first of these issues, which implies a conceptual understanding of requirements for the graphical presentation of a representation. Firstly, to gain insights into different aspects of rendering a study was conducted in the form of a questionnaire, the results of which are discussed in this paper. Section 2 details the current work, Section 3 discusses the questionnaire design and analysis, Section 4 presents the results of graphical and statistical analysis in the form of frequency distribution charts, means and standard deviations, hypothesis testing, correlations and ranking tests. Finally Section 5 concludes with the key findings. The study identifies some essential requirements for rendering to support human-computer symbiosis in conceptual design.

2 Current work

We tend to be accustomed to certain types of human computer interaction, where the humans give instructions and are responsible for all planning and initiation and the computers respond to the explicit instructions given. Most research in Human Computer Interaction (HCI) does not seek to change this current style of interaction. Licklider [3] argued that the computers should enable humans to cooperate in making decisions and controlling complex situations without dependence on predetermined situations. His vision of human-computer symbiosis challenges how humans and computers should interact and communicate. The identified three elements for symbiotic interaction: complementary and effective division of labour between humans and computers, an explicit representation in the computer of the human's mental model, and utilisation of non-verbal communication.

Rendering techniques enable the visualisation and manipulation of final products that were not previously possible using traditional geometric modelling techniques. Rendering is creating an image of objects by simulating the appearance of real world textures, colours, surface shadows and reflections [5]. In the computer graphics community, it can be classified into photo realistic and non-photo realistic. Despite much progress in efficiency and quality of photo realistic methods [6], the resulting photo realistic images may not always be the best way to present information. Non-photo realistic (NPR) rendering is now emerging as an alternative rendering method for computer generated images. These techniques use non-photo realistic methods, such as painting [7-10] and pen-and-ink [11-13], to create images and illustrations that present information about the object that may not be apparent in photographs or actuality. NPR methods are usually based on human perception and processes employed by the designer rather than realism.

Current traditional CAD systems require conceptual ideas to be defined into precise models, whilst allowing rendering. By retaining vagueness, vague rendering provides effective communication in conceptual design. In essence, with vague rendering the computer models closely reflect the mental model and also minimises the loss of information during mapping. Vague rendering presents to designers a range of tolerances in a concept representation. This enables designers to focus on the essence of the problem rather than unimportant details. The NPR methods convey an unfinished and sketchy look that encourages a review process and more accurately reflects the design concepts in conceptual design. Therefore, these images have characteristic vagueness within them. In this sense, vague rendering is the logical continuation of and is complementary to non-photo realistic rendering.

An NPR system acts as a procedural mediator between the computer world (hard data of the computer model) and the perception of the model (the output as seen by the designer) [14]. The visualisation and interpretation of the displayed information involves interactions of cognitive processes and their respective levels of representation. Thereby, the presentation of rendered images requires the accommodation of not only perception but also dynamics of how the meaning is processed. For this it is necessary to understand cognitive theories that explain how graphical information is understood and processed by humans. Some of the existing work on non-photo realistic rendering addresses the need for an approach for rendering that is based on cognitive theory [4], that is sufficient to communicate the intended message. Interacting Cognitive Systems (ICS) [15-17], used in the context of rendering, contribute to the understanding and interpretation of images.

ICS plays a role in the development of vague rendering to yield some insights into the structure and functionality of the representation being presented. Thereby, vague rendering mediates communication between humans and computers in developing a computational presentation appropriate to the way the designer thinks, or needs to think, about the representation. The cognitive theory supporting vague rendering will provide a basis for defining this new method to present vagueness and imprecision inherent in conceptual geometric representations.

3 Questionnaire design and analysis

To gain insights into the different aspects of rendering in conceptual design the research methodology adopted was in the form of a questionnaire. The questionnaire was designed with the objective to determine the requirements for rendering in conceptual design.

Owing to the difficulties of studying and impinging on actual design practise in industry, the study was analysed on education/academic group that does not have preconceived notion of the CAD systems. A total of sixty questionnaires were distributed to third year undergraduate product design students and faculty in Design, Manufacturing and Engineering Management Department, University of Strathclyde, resulting in forty-seven returned responses. The students already had spent two years carrying out sketching and rendering activities as part of their curriculum and can act as a basis to check any findings from actual design activities in following studies.

The questionnaire consisted of twenty-six questions and comprised of open-ended and scaled response questions. The open-ended questions gave scope for the respondents to express their ideas freely [18]. The scaled response questions allowed the measure of the respondents' attitudes towards the particular aspects. They also included the opportunity for the respondents to input their own choices.

The questionnaire addressed four aspects of rendering, such as the role of rendering, relevant approaches, vague rendering and limitations with current systems, in conceptual design to determine the requirements for rendering to support human-computer symbiosis.

a) To determine the *role of rendering* in the design process, the questions were based on:

- applicability of rendering in different stags of the design process,
- importance of rendering, with respect to communication of design ideas, time taken for designing, visualisation in its multitude of forms, and quality of the image, and
- assistance of rendering in design development.

b) To determine the *relevant approaches* to rendering, the questions included:

- importance of hand drawn and computer renderings, and
- importance of photo realistic and non-photo realistic methods.

c) To gain insights into the nature of *vague rendering,* the questions were based on:

- precision of concepts used, such as vague and precise,
- presentation of vague geometry using lines, vague shape and vague surface,
- parameters associated with rendering techniques, that vary the style of the resulting images, and
- factors influencing rendering.

d) To determine the *limitations* with current systems, it is required to determine

- dissatisfying factors with present rendering tools.

The results of the open-ended questions were exemplified by the actual quotes stated by the respondents. The quotes, being the most frequent answers in the questionnaire, also serve to show the respondent's statements, rather than forming a statistical extraction. The data collected from the scaled response questions was analysed statistically. Frequency distribution bar charts were used to illustrate the data from the sample graphically. The frequency distribution is a summary of the frequency of individual values or ranges of values for a variable [19]. Statistical analysis, such as descriptive and inferential, was used to represent the opinion of the population in general. The statistical programme SPSS for Windows 10.0 ('Statistical package for the Social Sciences) [19] was used to analyse the data.

With descriptive statistics, descriptions were made with what the data shows. It describes the basic features like mean and standard deviation of the data in the study. The Mean (*M*) or Average is the most commonly used method of describing central tendency of a sample (*N*). The Standard Deviation (*SD*) gives a measure of how much spread out the data is around the mean.

With inferential statistics, conclusions were reached about the given data. From the sample data, inferential statistics tries to infer what the population, in general, might think and to make judgments of the probability (*p*) that an observed difference between groups is a significant one or one that might have happened due to random events in the study [19]. The usual significant levels used are 0.01 or 0.05. That is, a statistical significance of 0.01 ($p < 0.01$) or 0.05 ($p < 0.05$) means that there is probability of 1% or 5% chance that the effects seen are due to random events. Inferential statistics like hypothesis testing, correlation analysis and ranking tests were used to make inferences from the data to more general conclusions. Hypothesis testing is a statistical method that uses sample data to test claims/hypothesis about a population parameter, such as mean, standard deviation and a proportion or percentage. Correlation analysis was used to identify the nature of relationship between different sets of variables. The Pearson correlation coefficient (*r*) is a numerical measure of the amount of linear association between two sets of variables. It ranges in number from +1.0 to -1.0. So as the number tends to ±1.0 there is either strong positive or negative correlation. A non-parametric test such as Wilcoxon signed rank test was used to compare two populations based on matched pairs. This test helps to determine whether ranks in one group of the paired data are typically larger or smaller than ranks in the other groups. This test is applied when the sample data are ranks, that is, ordinal data rather than direct measurements.

The results were collated using the following sets of encodings: for numerical responses 1 (0-20%), 2 (21-40%), 3 (41-60%), 4 (61-80%), 5 (81-100%); for responses relating to importance 4 (great importance), 3 (some importance), 2 (no importance), and 1 (do not know); and for type of information 1 (very precise), 2 (precise), 3 (vague and precise), 4 (vague) and 5 (very vague). However, the graphical illustrations does not display the responses relating to 'do not know' option in the questionnaire.

4 Results

The significant results extrapolated from the study are presented in this section.

4.1 The role of rendering in the design process

4.1.1 Applicability

The respondents were questioned on how often they used rendering in different stages of the design process, such as *requirements specification*, *conceptual*, *embodiment*, *detailed* and *manufacturing*. They were provided with multiple choices for the range of applicability varying from 0 to 100% in steps of 20% (i.e. 0-20, 20-40, 40-60, 60-80 and 80-100). The higher the range of values the higher the *applicability* and vice versa.

The frequency distribution bar chart, Figure 1, shows the opinion of the respondents graphically.

- Requirements specification ($M = 1.2$, $SD = 0.58$): 87% of respondents use rendering in the range of 0-20%. This implies that the majority of the respondents felt that rendering is not relevant in the requirements specification stage.
- Conceptual ($M = 3.0$, $SD = 1.07$): 38% of the respondents use rendering in the range of 40-60%. This shows that rendering is relevant in the conceptual stage since the range of applicability is higher than 50%.

– Embodiment (*M* = 3.9, *SD* = 0.89): 38% of the respondents use 60-80% of rendering in embodiment stage. This shows that rendering is applicable in this stage since the range of applicability is higher than 50%.

– Detailed design (*M* = 3.9, *SD* = 1.21): 43% of the respondents felt that rendering is highly relevant for the detailed stage as they use rendering in the range of 80-100%.

– Manufacture (*M* = 2.7, *SD* = 1.27): Rendering is not that relevant in the manufacturing stage as 28% respondents use it in the range of 20-40%.

Hence, the bar chart shows that conceptual, embodiment and detailed design stages are considered to be the most relevant for rendering.

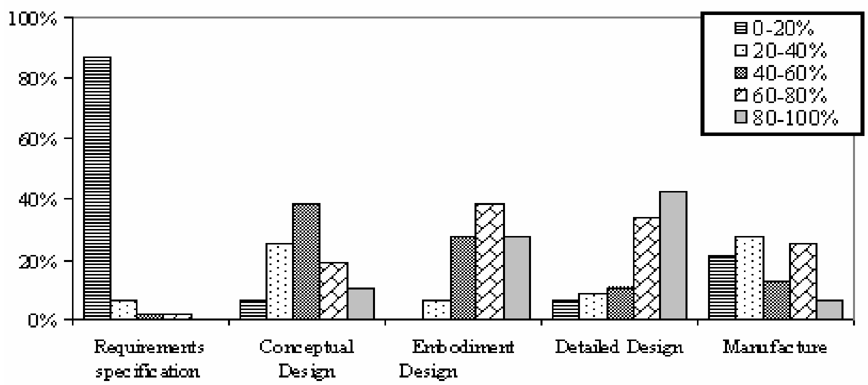

Figure 1. Applicability of rendering in the design process (in %)

4.1.2 Importance of rendering in conceptual design

The respondents were asked to indicate the importance of rendering with respect to *communication*, *time*, *visualisation* and *quality*. Figure 2 shows that 43% of the respondents felt rendering in conceptual design is very important for communication (*M* = 3.4, *SD* = 0.65), 28% felt rendering to be very important for reducing the time (*M* = 3.0, *SD* = 0.89), 62% felt rendering to be very important for visualisation (*M* = 3.7, *SD* = 0.48) and only 17% felt that rendering is very important for depicting quality (*M* = 2.7, *SD* = 0.73). This clearly indicates that quality is considered not important in conceptual design and hence not considered for further ranking of the elements.

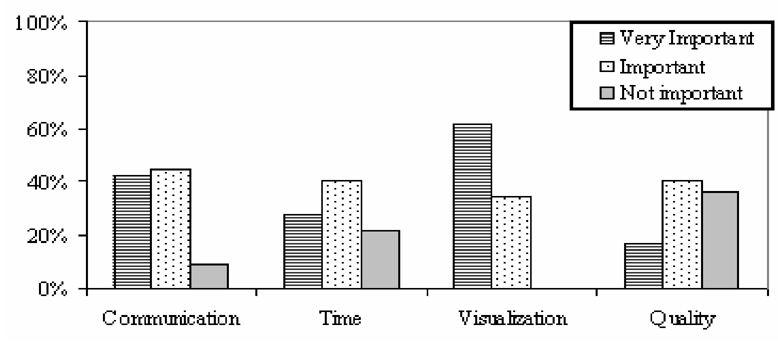

Figure 2. Importance of rendering

The Wilcoxon signed rank test was conducted for ranking between communication, time and visualisation. From Table1, communication, time and visualisation have positive ranks for 29 (21 + 8), 15 (11 + 4) and 42 (19 + 23) cases respectively, combined with a significance at a 0.05 level. This gives sufficient evidence to indicate that visualisation is rated higher than communication and time. In summary, the ranking of the importance of rendering in conceptual design as shown by statistical and graphical analysis is visualisation, followed by communication and then time.

Table 1. Ranking of the elements

	Ranks	No. of cases
Time Vs Communication	Negative ranks Positive ranks Ties	21, time < communication 11, time > communication 12, time = communication
Visualisation Vs Communication	Negative ranks Positive ranks Ties	8, visualisation < communication 19, visualisation > communication 17, visualisation = communication
Visualisation Vs Time	Negative ranks Positive ranks Ties	4, visualisation < time 23, visualisation > time 17, visualisation = time

4.1.3 Assistance of rendering in design development

Respondents were provided with the opportunity, through an open-ended question, to indicate how rendering assists in design development. The respondents pointed out the assistance of rendering:

- in aesthetic development and to see the product when it happens,
- in promotion of ideas, visualisation and manipulation, realism,
- to conceive a product by applying real features of the product through the computer before actually a product is made, and
- to provide a realistic representation of how the product looks when it is manufactured.

4.2 Relevant approaches

4.2.1 Hand drawn and Computer renderings

The respondents were questioned whether *hand drawn* or *computer renderings* were the appropriate way to convey a designer' s idea. The *mean values* for hand drawn renderings and computer renderings were 3.7 (*SD* = 0.99) and 3.9 (*SD* = 0.94) respectively. This implies that computer renderings are the most appropriate to convey design ideas.

The opinions for hand drawn renderings for conveying their ideas were:

- carry ability to identify the status of the idea: key elements, relationships, annotations are important in supporting this,
- fast and flexible, gives ideas quickly and effectively, and
- high speed and instant changes.

Some opinions for computer renderings were:

- get full attention of the client by giving an indication of final appearance of the product and showing different angles of the product relatively easily,
- gives better visualisation and a full view of the product, and

– more appropriate and fast, more flexible and synchronous, more consistent and neater.

4.2.2 Photo realistic and Non-photo realistic rendering

According to the bar chart, Figure 3, 11% of the respondents felt that *photo realistic* (M = 2.6, SD = 0.91) was very important, whereas 6% of the respondents felt *non-photo realistic* (M = 2.7, SD = 0.77) as very important. This is in context of 32% considered photo realistic as important compared to 60% for non-photo realistic rendering. In conclusion, only 43% considered photo-realistic as very or important compared to 66% for non-photo realistic.

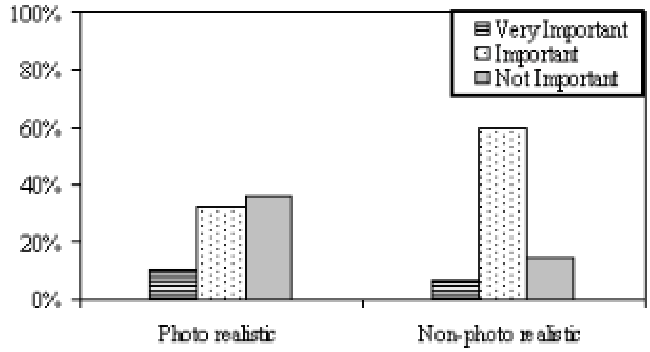

Figure 3. Photorealistic and Non-photorealistic rendering

4.3 Vague rendering

4.3.1 Precision of concepts used

The respondents were asked about the precision of the concepts used in conceptual design. They were given a wide range of options from *very vague* to *very precise*. An overview of the hypothesis testing conducted, to determine the precision of concepts used, is shown in table 2. In the table, the null hypothesis represents a hypothesis under test. The test statistic Z, gives how many standard deviations from the assumed mean is the average of the sample using equation 1, is used to determine whether to accept or reject the null hypothesis.

$$TestStatistic\mathrm{Z} = \frac{\overline{\mathrm{X}} - \mu}{StandardError} \qquad (1)$$

In equation 1, $\overline{\mathrm{X}}$ is the sample mean, μ (assumed mean) is the population parameter and the standard error is the standard deviation of the sample mean. It indicates by how much the sample mean would be expected to differ if other samples from the same population are used. The *mean value* ($\overline{\mathrm{X}}$) and *standard error* for the precision of concept representations in the study is 3.3 and 0.15 respectively. The hypothesised value of μ is 5,4,3,2 and 1, for the parameters (very vague, vague, vague and precise, precise and very precise) specified in the null hypothesis (see Table 2), that is substituted sequentially in equation 1, to test the null hypothesis.

The test statistic Z is compared to the critical value for a standard normal distribution, to decide whether to accept or reject the hypothesis tested. Critical values indicate the beginning of the rejection (critical) region that would lead to rejection of the null hypothesis. If the test statistic falls in the rejection region, the null hypothesis is rejected. The critical value depends on the significance level and nature of the null hypothesis tested. The significance level is the probability of wrongly rejecting the null hypothesis when it is actually true. The usual values used are 1% or 5%. The nature of the null hypothesis tested is either one tailed or two tailed. The word tail indicates the area of rejection beneath the normal curve (see Figure 4).

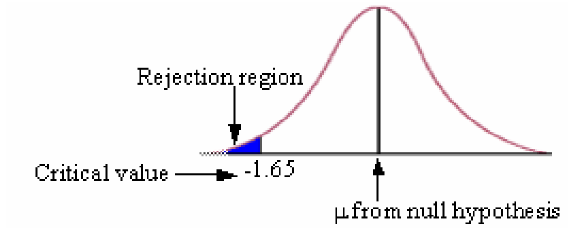

Figure 4. Normal distribution: One-tail test

Lets postulate the hypothesis, as the precision of concepts used is very vague. Since the hypothesis states the direction of the result, one tail test is justified in this hypothesis testing. The critical value at 5% significant level for a one-tail test is –1.65 standard deviations from the assumed mean (μ). A one-tail test rejects the hypothesis for values of test statistic less than –1.65 (see Figure 4).

For example:

$$TestStatisticZ = \frac{3.3-5}{0.15} = -11.33 \quad (2)$$

The test statistic for the hypothesis postulated (see equation 2) is less than the critical value hence the hypothesis is rejected. Thereby the next degree of precision is tested until the hypothesis stated is accepted. As seen in table 2, the precision of concepts used in conceptual design varies from *fairly vague* to *very precise*.

Table 2. Hypothesis testing for precision of concept representations

Null hypothesis		Test statistic, Z	Critical value	Conclusion
Precision of concepts used	**very vague**	-11.33	-1.65	Reject
	vague	-4.67		
	fairly vague (vague and precise)	2.0		Accept
	precise	8.67		
	very precise	15.33		

Reasons given, in an open-ended question, for using vague concepts were:

- at conceptual design not all details are known,
- conceptual rendering is an early indefinite stage, thereby no need to be precise or accurate, and
- most clients are happy to see what the aesthetics will do for their product. We make it clear from the sketches by showing form, layout, main features rather than detail.

Reasons for using precise concepts were:

- conceptual design is just initial stage so rendering if done should be precise,
- the intended meaning is shown if it is accurate,
- rendering specifies actual features on a product so all parameters should be precise/accurate, and
- vagueness is difficult in a medium that works with precision - tend to post process afterwards if required.

4.3.2 Presentation of vague geometry

Vague geometry can be presented by using *lines*, *vague shape* and *vague surface*. The respondents were asked to indicate the importance of these during the generation of concepts.

Figure 5 shows that lines (66%), vague shape (43%) and vague surface (45%) are *equally important* as other product aspects (such as material, colours and light) during the generation of concepts.

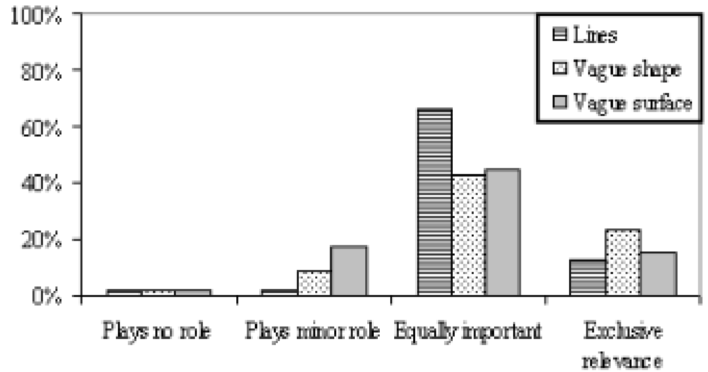

Figure 5. Vague geometry

The lines, vague shape and vague surface were compared to check for any correlation among them. The correlation of lines and vague shape, lines and vague surface and vague shape and vague surface are found to be 0.49, 0.46 and 0.69 respectively, which were significant at 0.001 level. The high positive correlations indicate that a strong relationship exists between each of them.

4.3.3 Rendering parameters

Tuning of rendering parameters, such as colours, lights, line factor, mapping, material, shadows, surfaces, textures, transparency and vagueness, is essential for creating the type of images desired. The respondents were asked to indicate the importance they attribute to these parameters. Figure 6 shows that 47% of the respondents felt colours of great importance, 53% felt light to be of great importance, 34% of the respondents felt line factors to be of some importance, 38% felt mapping to be of some importance, 51% felt material to be of some importance, 53% felt shadows of some importance, 66% felt surfaces of great importance, 53% felt texture of great importance, 49% felt transparency to be of some importance and 28% felt vagueness to be of some importance.

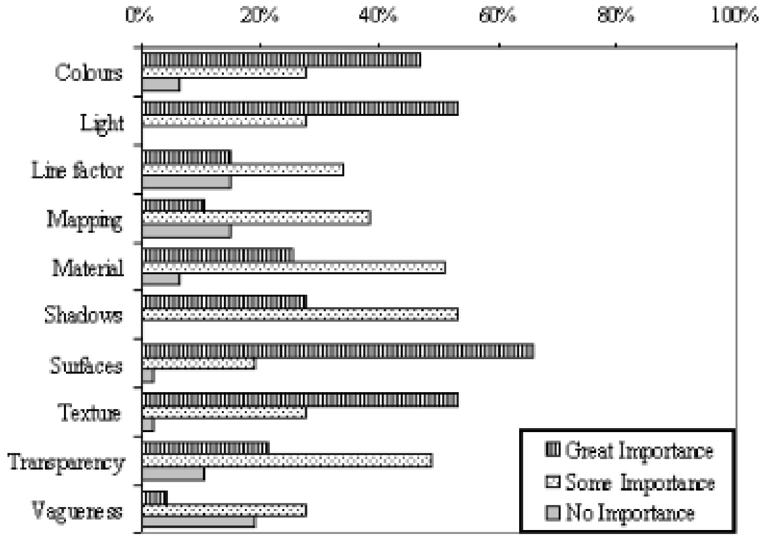

Figure 6. Rendering parameters

4.3.4 Factors influencing rendering

The Pearson correlation analysis was performed to find out the intercorrelations between the factors influencing rendering. Table 3 presents 8 $\times$ 8 correlation matrix. From the resulting 64 combinations, 12 of them had a strong correlation, with an absolute value of more than 0.3 combined with significance either at the 0.01 or 0.05 levels. The dash in the correlation matrix indicates the correlation of the factor with itself (=1.0). The blank cells indicate the combinations that had correlations less than 0.3. The high positive correlations in the table, between factors influencing rendering, indicate that a strong relationship exists between each of them respectively.

Table 3. Intercorrelations between factors influencing rendering

	Aesthetics	Alternative solutions	Communication	Dimensionality	Expression	Image quality	Rendering style	Speed of rendering
Aesthetics	-		0.4	0.6	0.5	0.7	0.5	
Alternative solutions		-						
Communication			-	0.4	0.4	0.6	0.4	
Dimensionality				-		0.6	0.5	
Expression					-			
Image quality						-	0.5	
Rendering style							-	
Speed of rendering								-

To explore which factors influencing rendering correlate most with specific rendering parameters, correlation analysis was again performed. Table 4 presents the combinations of the factors and parameters that had a strong correlation, with an absolute value equal to or more than 0.3 combined with significance at 0.01 level. The blank cells indicate the combinations that had correlations less than 0.3. The high positive correlations in the table, between factors influencing rendering and rendering parameters, indicate that a strong relationship exists between each of them respectively.

Table 4. Correlations between factors influencing rendering and rendering parameters

	Colours	Light	Line factors	Mapping	Materials	Shadows	Surfaces	Textures	Transparency	Vagueness
Aesthetics							0.4	0.4		
Alternative solutions			0.6	0.3						0.5
Communication	0.5									
Dimensionality										
Expression										
Image quality							0.6			
Rendering style		0.4						0.5	0.4	
Speed of rendering										

4.4 Limitations with the current systems

4.4.1 Dissatisfaction with present rendering tools

Figure 7 shows that 32% of the respondents felt that absence of alternative solutions, absence of exploring new ideas, absence of a sketchy look and 30% felt lack of differentiation of essential and unessential information as the most dissatisfying factors with present rendering tools.

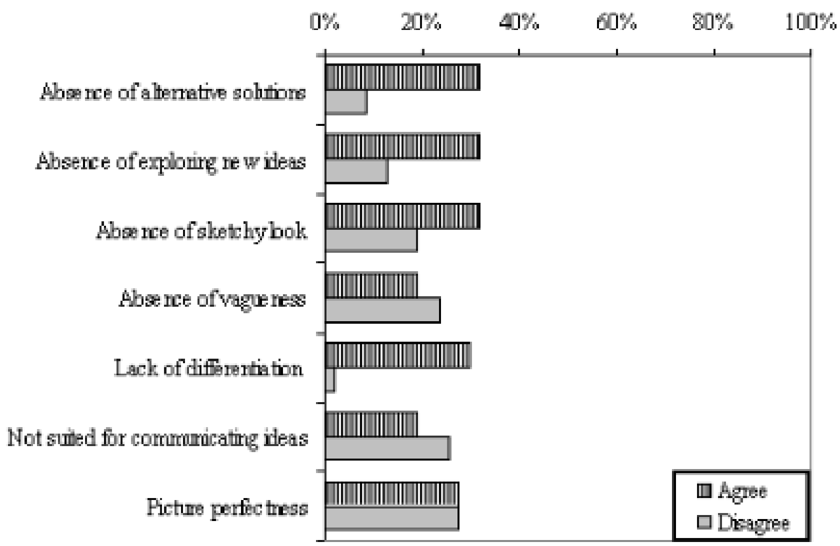

Figure 7. Dissatisfying factors

The respondents expressed, in an open-ended question, dissatisfying factors in present rendering tools:

- do not provide for making meanings at sketch level explicitly,

- definition of abstract geometry,
- interaction model not well matched to designers way of working at concept level,
- modern tools lack different types of lighting,
- no expression of constraints and easy way to edit structure,
- time consuming, difficult to learn quickly, and
- to get sketchy output work has to be done photo realistically then consider making it sketchy.

Possible solutions given by respondents for the problems encountered with present tools were:

- cater for sketching loosely while identifying lines, colours and shapes
- one that generates detailed drawings from sketches
- supports an underlying model of meaning, understandable but linkable to the surface graphical model,
- support developing sketches into real exportable models (to CAD system for further development), and
- use of Photoshop effects can help give rendering a sketch look which have to be started with finished computer rendering.

5 Conclusion

Rendering in conceptual design has received less attention to date, compared to later stages of design, despite potential advantages of having rendered representations at the earliest opportunity. The results from the study on different aspects of rendering suggest that:

- Rendering can be extended in conceptual design to investigate and inspire different ideas or concepts, specifically for *visualisation* of design in its multitude of forms and *communication* of design ideas (Section 4.1).
- *Non-photo realistic rendering* is considered to be *very important* in conceptual design (Section 4.2).
- The precision of concepts used in conceptual design varies from *fairly vague* to *very precise*. *Lines*, *vague shape* and *vague surface* that can be used to present vague geometry are *equally important* as other product aspects (such as colour, lighting and material) during the generation of concepts (Section 4.3).
- The *absence of a sketchy look*, *lack of differentiation between essential and non-essential information*, *absence of alternate solutions* and *absence of exploring ideas* are some of the most *dissatisfying factors* (Section 4.4).

The findings about the nature of vague rendering, the strong correlations found in tables 3 and 4 and the identified limitations with the current systems, serve as a basis for developing vague rendered presentation styles and determining the requirements for rendered representations. With respect to establishing a greater interaction between human designers and present CAD systems, further validation of the findings have been met by mapping them with existing and new (vague rendering) presentation styles:

- Lines have been used for the graphical presentation of vagueness inherent in a concept representation.

  By retaining vagueness, vague rendering provides effective communication in conceptual design. In essence, with vague rendering, the computer model more closely reflects the mental model and minimises the loss of information during mapping. Vague rendering presents a range of tolerances in a concept representation. This enables designers to focus on the essence of the problem rather than unimportant details.
- The identified limitations with current systems, such as no support for sketchy look, differentiation of essential and non-essential information, and promotion of alternate solutions and exploring new ideas, have been set as the presentation requirements for rendered representations in conceptual design.

The methodology, questionnaire, adopted for the study proved to be a valuable tool for gaining insights into different aspects of rendering in conceptual design. The scaled format questions facilitated quick completion and a detailed quantification of results. Problems did arise with respect to the terminology used in the questionnaire and measures were taken in subsequent designs by providing definitions. Although the responses varied from respondent to respondent, the results were extrapolated to the general education/academic population using inferential statistics. The staff in the department with more than five years of experience in engineering design offered the most valuable information in the open ended questions.

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References

[1] Guan, X., K.J. MacCallum, and A.H.B. Duffy, “Classification of Geometric Design Information and Manipulation for Vague Geometric Modelling”, in Workshop on Knowledge Intensive CAD, Carnegie Mellon University, Pittsburgh, USA, 1996.

[2] Burns, K.J., “Mental models of line drawings”, Perception, 30(10), 2001, p. 1249 - 1261.

[3] Licklider, J.C.R., “Man-Computer Symbiosis”, IRE Transactions on Human Factors in Electronics, HFE-1, 1960, p. 4-11.

[4] Duke, D.J., P.J. Barnard, N. Halper, and M. Mellin, “Rendering and Affect”, Computer Graphics Forum, 22(3), 2003, p. 359-368.

[5] Pearsall, J., “The New Oxford Dictionary of English”, ed. P. Hanks, Oxford University Press, 1998, 0-19-861263-X.

[6] Kajiya, J.T, “The Rendering Equation”, in Proceedings of the 13th Annual Conference on Computer Graphics and Interactive Techniques, ACM Press, New York, USA, 1986.

[7] Curtis, C.J., S.E. Anderson, J.E. Seims, K.W. Fleischer, and D.H. Salesin, “Computer Generated Water colour”, Computer Graphics, 31(SIGGRAPH'97 Proceedings Issue), 1997, p. 421- 430.

[8] Litwinowicz, P, “Processing images and video for an impressionist effect”, in Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques, ACM Press, New York, USA, 1997.

[9] Meier, B.M, “Painterly Rendering for Animation”, in Proceedings of ACM SIGGRAPH 96, Computer Graphics Proceedings, Annual Conference Series, ACM Press, New York, 1996.

[10] Salisbury, M., M.T. Wong, J.F. Hughes, and D.H. Salesin, “Orientable Textures for Image-based Pen-and-Ink Illustration”, in Computer Graphics (SIGGRAPH'97 Proceedings Issue), Addison Wesley, 1997.

[11] Winkenbach, G. and D.H. Salesin, “Computer Generated Pen-and-Ink Illustrations”, Computer Graphics (SIGGRAPH'94 Proceedings Issue), 28(4), 1994, p. 91-100.

[12] Hsu, S.C., I.H.H. Lee, and N.E. Wiseman, “Skeletal Strokes”, in Proceedings of the 6th Annual ACM Symposium on User Interface Software and Technology, Atlanta, ACM Press, New York, USA, 1993.

[13] Hsu, S.C. and I.H.H. Lee, “Drawing and animation using skeletal strokes”, in Proceedings of ACM SIGGRAPH 94, Computer Graphics Proceedings, New York, 1994.

[14] Schofield, S., “Non-photorealistic Rendering: A Critical Examination and Proposed System”, PhD Thesis, in School of Art and Design, Middlesex University, United Kingdom, 1994.

[15] Barnard, P.J. and J. May, “Cognitive Modelling for User Requirements”, in Computers, Communication and Usability: Design issues, Research and Methods for Integrated Services (North Holland Series in Telecommunication), Elsevier Science, Amsterdam, 1993.

[16] Barnard, P.J. and J. May, “Interactions with Advanced Graphical Interfaces and the Deployment of Latent Human Knowledge”, in Proceedings of the First Eurographics Workshop on the Design, Specification and Verification of Interactive Systems, Springer-Verlag, 1995.

[17] Duke, D.J., P.J. Barnard, D.A. Duce, and J. May, “Syndhetic Modelling”, Human Computer Interaction, 13(4), 1999, p. 93-158.

[18] Fraser, L. and M. Lawley, “Questionnaire design and administration: A practical guide”, Wiley, 2001, 0-471-34292-0.

[19] Howitt, D. and D. Cramer, “A guide to computing with SPSS 11 for Windows”, Revised Edition, Pearson Higher Education, 2003, 0131399837.

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