Colour management is a socio-technical problem

ABSTRACT

This paper describes how achieving consistent colour reproduction across different devices is a complicated matter. Although there is a technological infrastructure for managing colour across devices this is very rarely used as intended. This infrastructure has been created by modelling the problem of colour management as a wholly technical one. In this paper we illustrate the importance of understanding the management of colour as a socio-technical problem, by describing the findings of a multi-sited ethnography of designers and print shops. Our analysis of the ethnography reveals that designers build up *practical, tangible, visual* understandings of colour and that these do not fit with the current solution, which requires users to deal with colour in an *abstract* manner. This paper builds on previous research in CSCW which has considered the importance of socio-technical *systems*, bringing the work into a previously unexplored domain. It shows how an understanding of the social can also be central when designing technical infrastructures.

Author Keywords

Colour, colour management, graphic design, printing, ethnography, ethnomethodology, socio-technical design

ACM Classification Keywords

H.5.3 [**Information interfaces and presentation**]: Group and organization interfaces - *Computer-supported cooperative work, organization design*; J.4 [**Computer applications**]: Social and behavioural sciences - *Sociology*; D.2 [**Software**] Software engineering; H.1.2 [**Models and principles**]: User/machine systems - *Human factors*

INTRODUCTION

In this paper we examine the problem of colour production in the digital design-to-print workflow. Getting the right colour on a printed product from a digital file is not straightforward; indeed it often involves a lot of coordinated work by designers and print shops [14]. Problems arise because different devices produce colour in different ways and this can lead to markedly different results when an image on one device is transferred to another device, e.g. from screen to print. The current technology that is designed to address the problem of colour consistency across devices – the Colour Management (CM) infrastructure – takes a wholly technical approach to the problem. Indeed it has been described by colour scientists as a 'technically correct' solution [Woolfe, personal communication]. However, it is only very rarely used as intended. We suggest that the problem of colour production is a *socio-technical problem* and needs to be considered as such if a more widely successful solution is to be produced and implemented.

To better understand the socio-technical nature of the problem, and why the current technical solution was failing, we carried out a multi-sited ethnography of a number of different design houses and print shops to understand how they managed colour in their work. We observed a range of collaborative, ad hoc practices between print shops and designers that were employed to achieve successful (or good enough) colour. We consider just how the CM solution impacts upon the work of practitioners and is understood by them in the real world of colour production. We propose that designers and printers build up *practical, tangible, visual* understandings of colour and that these do not fit with the current solution, which requires users to have a *mathematical* understanding of colour (i.e. it is described in mathematical spaces). We believe that taking a *socio-technical* approach to the problem can reveal new opportunities for technology design.

RELATED WORK

The importance of considering the social aspects of work in the design of the technology has been established for some time. For example, in the early 1990's, Gentner and Grudin described how computer use, and therefore interface design, was changing [7]; moving from an interface for engineers, representing the engineering model of the machine; to single 'everyman' users, where the interface took in concepts from psychology; to groups of users, where it needed take into account the social and organisational context of use. This latter concept is foundational for CSCW, i.e. computers as collaborative and therefore inherently social, tools. At the same time workflow systems

- systems that manage the coordination of work along a process - were becoming popular [1]. They were commonly designed by abstractly modelling the processes of the work (using data flow diagrams and so on), resulting in a process description which would then be enacted in the technology. The process description is at the heart of workflow technology, describing the sequence of actions to be undertaken so that the process is carried out correctly. The system then drives user actions according to the sequence embedded in the system [5]. It was in critique of workflow systems that the idea of socio-technical *systems* really came into its own. Researchers examining workflow systems which were failing or inadequate (e.g. [2] or [3]) and those working on workflow system redesign (e.g. [5], [10]) reported how people interpret processes very flexibly to get the work done. Process models commonly omit vital details of how real work is organized. Hence the workflow systems built on these process models either restricted workers' activity preventing the work being done, were 'worked-around', or were relegated to mere accounting rather than coordination tools. This led the call for creating systems which were designed with a clear understanding of the social practices of work rather than on the basis of an idealised, or rationalised, strict process model. Dourish et al, for example, suggested a system which mediated between the real work practices and the process model [5] In this way, it was felt that systems would resonate better with the actual circumstances of the work. This research has moved on and now encompasses ideas such as the fact that any new system will change the way people work, and so as well as designing for 'the social', systems should have a period of 'domestication' when being deployed where further changes can be made and evaluated [8].

The idea of socio-technical design is central to this paper. However, we find it necessary to delve beneath workflow and, rather in a manner suggested by Star and Ruhleder [16], to examine the relations between a set of practitioner methods and understandings and the instantiation and workings and of the technical CM infrastructure. We believe that the idea of socio-technical design as applied to infrastructures has not been widely studied in CSCW. Although there is some work on how can people make infrastructures work, e.g. for cyber-infrastructures [11], differentially in this case the CM infrastructure is misunderstood, worked against or ignored.

While a study of graphic design has already been presented in the CSCW arena [13], it only touched on the problem of colour in the lightest fashion. We believe, apart from being interesting and novel in itself, the study described in this paper provides insights into the relationships between cooperative practice, workflows and infrastructure in technically complex domains. In the following sections we detail the problem of colour production and the findings of an ethnographic study of graphic designers and printers, which leads us to a discussion on colour reasoning and the technical infrastructure. We finish with some design directions.

THE PROBLEM OF COLOUR PRODUCTION

Achieving consistent colour across devices and applications is a problem due to the varying ways colour is represented and produced in digital and non-digital media. For example, most designs produced by graphic designers are created using software applications and viewed on their computer screens, which display colour using Red, Green and Blue (RGB) light-emitting diodes (LEDs). Most print machines, on the other hand, produce colour by applying Cyan, Magenta, Yellow and Black (CMYK) inks or dry toner particles on a substrate such as paper. The different methods of colour production and media of presentation leads to a situation where ostensibly the same colour can appear different to the viewer on screen versus in print. For example, colours on screen often appear brighter.

Colour data is represented using numerical colour spaces, each space is a 'language' to describe colour. Every device has its own colour space, in which the colours the device creates are plotted and described using integers. Each colour space has a different relationship between colour and the numbers used to encode the colours. Thus the same set of colour values can look different in two different colour spaces. The result is that different devices, even of the same type, e.g. two different printers or monitors, can represent colour in different ways. Furthermore, different devices have different colour 'gamuts', that is, different ranges of possible colours that they can create. Hence colours that can be reproduced on one device may be out of range for another device. Out of gamut colours must somehow be converted to similar colours within the target device's gamut. Depending on the consonance between the gamuts of two devices and the specific mapping algorithm used, the discrepancy between the translated instances of the 'same' colours can vary quite considerably.

There is a technical infrastructure in place, ICC Colour Management [9], which is proposed as the standard through which different devices and software applications translate the colour information contained in digital documents. It therefore operates in the background of a design and print workflow whether the users are aware of it or not. This infrastructure requires all parties involved in a workflow to understand and strictly adhere to its protocols [12]. This, is a considerable overhead for both print providers and their customers – both in terms of knowledge required to design and implement the workflow and the need for close coordination within and across organisational boundaries [14]. The net effect of this is that colour management as has been observed elsewhere [15], is rarely used as intended. Even where a file is tagged with colour management information, it is often ignored by print shops because they lack confidence in their customers' correct usage of it.

There are several consequences of this. Firstly customers are often disappointed by the colours returned to them by

their print supplier, as they do not match closely enough what they were expecting. Secondly, when colours are flagged as being very important designers and printers work together to specify, match and test colours. In other cases print shops feel professionally obliged to engage in additional work to achieve aesthetically pleasing printed products. What we seek to demonstrate in this paper is that the problem of achieving good quality colour is best understood as a socio-technical one. Designers and print shops collaboratively work to achieve good colour. Complications arise because their practices are often not in line with ICC Colour Management, the technical solution which is embedded in the software and devices they use. They, for the most part, have only partial understandings of the underlying CM infrastructure and are at times almost oblivious to it. This can lead to unexpected and confusing effects and provokes extra work to avoid or correct these problems. Additionally, it is often difficult to understand – even for domain experts – just why a particular problem has occurred, where it is located and how to solve it.

METHOD

Between 2006 and 2008 we carried out a multi-sited ethnography of graphic designers and print shops to understand the work of creating and producing colour in digital and print media. We visited a number of graphic design houses (3) and print shops (3) for periods varying between two-days and three weeks. The sites were mainly in Europe (plus one US site). The research was undertaken in conjunction with colleagues in our sister organisation in the US, who visited sites in the US and Canada and whose findings corroborate ours. Our primary method of research is observation, supplemented by in situ interviewing. Data was collected through field notes, audio and video recordings, photographs and samples. Undertaking a multi-sited ethnography enabled us to get an understanding of the variety of practices at a range of different sites, with different clients, work organisations, etc., in a range of countries. Our orientation is ethnomethodological [6], which has been found to be a fruitful approach for understanding work and technology use [4]. We analysed the situated, collaborative practices designers and printers used to achieve good quality colour in their documents, products and so on.

THE COLLABORATIVE ACHIEVEMENT OF COLOUR

Our field studies revealed a variety of methods employed by designers and printers to address the problem of colour production. These methods typically involve direct collaboration between designers and print shops, dealing with visually matching and testing samples and in some cases amount to the creation of ad-hoc socio-technical workflows for specific jobs. In this section we explicate the collaborative practices involved in achieving good colour, illustrating key methods with examples.

Use of Pantone swatch books

In the print industry *spot colours* are a widely used means to specify certain colours within a document. Spot colours are printed using a specially produced single ink colour in a single run (as opposed to combinations of colours (CMYK) in process colour printing) and are often used for flat coloured elements in designs such as company logos. The most common standard for specifying spot colours is provided by the Pantone Corporation through the Pantone Matching System (PMS). The PMS comprises a series of colour reference guides for different kinds of print devices and substrates, where a designated colour refers to 1) an ink formula (e.g., British Racing Green is specified as PMS 5535), or 2) to a CMYK (process colour) mix – which might be, but is not necessarily, the equivalent of an ink formula. The CMYK specifications are necessary because, as well as being more expensive, not all offset and very few digital print machines are capable of using Pantone inks. Spot colours therefore are often converted to the CMYK specifications. Depending on the colour, because of gamut issues and such like, there can be quite a difference between the ink formula and the nearest CMYK equivalent. When using Pantone books and charts, it is important to understand that practitioners need to use the *appropriate book for the appropriate machine and substrate.* For example, PMS 5535 will appear slightly different when printed by digital or off-set machines.

Figure 1: Digital pantone swatch chart

We observed a widespread use of Pantone swatch books and charts (Figure 1) for selecting and controlling colour in all the design houses we visited. Each swatch chart shows samples of the colour for each labelled spot colour or process colour mix. In the cases of best practice, the designers use print technology and substrate (e.g. coated/uncoated paper) appropriate pantone swatch books. This requires knowledge of which print device is going to be used and therefore co-ordination with the print provider. However, some design houses use Pantone swatch books that were not 'correct' for the print technology and substrate they were going to use. In these cases, the relationship between the chosen Pantones and the actual printed colours can vary significantly. The variation in colour between the same numbered Pantone as realised on different devices is not a widely understood fact; e.g. if a

colour is chosen from a standard off-set Pantone book but the file is then printed on a digital print machine there may be a considerable difference.

Pantone swatches are often used because they are a *visual*, *tangible* way of identifying colour samples and sharing them between designers and customers. One strategy we observed is for designers to initially work on screen, trying various colours out in their design. Once the designer identifies a suitable colour or palette (set of colours), they look for the closest match(es) on a Pantone swatch book by comparing the swatches to the colours on screen. They then note the best matched spot or CMYK colour (from the swatch book) and encode those values in the file. Encoding those values in the file can change the appearance of the colour on screen, so at this stage trust passes from the visual appearance of the screen to confidence in the process whereby this specific matching and conversion took place. The print device will then print out the colour directly from the specified values. Success depends on the appropriateness of the chosen Pantone guide. Furthermore, it should be noted that design software offers the functionality to automatically convert on-screen colours into their CMYK breakdowns. Practitioners need to be especially careful if they choose this route because these breakdowns can differ from those in the printed guide.

For example, a designer was producing a design for a flyer for a takeaway shop (Figure 2). After choosing some colours on screen and confirming with the customer, the designer matched the two key greens viewed on screen with pantones from a pantone swatch chart provided by the printer. The CMYK values for these greens were then encoded in the file.

Figure 2: Deli flyer

Using a pantone swatch book for the print machine you will be printing on allows the designer to understand, view and control colours to a reasonable extent because they specify colours that can be achieved on that machine. This method allows the ***matching of colours by eye*** which is one of the designers preferred methods (although they are aware that matching colours individually between screen and swatch book is not directly equivalent to seeing the colours printed together). Also, it is a relatively straightforward three step procedure: 1) choose colour on screen 2) choose match from swatchbook 3) encode value in file. When using digital printing, this method implies, if not necessarily a long term relationship between print shop and design house, that the designers at least know what print shop they will use when the create the design and contact them for a swatchbook in advance.

Work in default CMYK colour space to help with gamut issues

Two design houses we visited work by default in a CMYK 'emulation' space when they are producing a printed product to minimise the discrepancy between what they see on screen and what will eventually be printed. This can be done through the menus on most design applications. There will, in general, be a greater consonance between what is seen on screen and what will be printed and less likelihood of choosing out-of-gamut colours. However, understanding just how what appears on screen will relate to a print is still complicated because transforms will still take place when moving from one colour space to another.

Preferred palettes, 'known about' and 'simple' colours

Designers often had preferred palettes and 'known about' colours. These were (sets of) colours that, by experience, designers had found seemed to print well. This was probably not simply a matter of perceived consonance between screen and print but was also to do with having ***seen the colours printed a number of times and liking the results*** – i.e. they looked good, and had shown themselves to be 'trustworthy'. For this reason, they might guide customers to one of those colours if they felt it was appropriate for the product. On the other hand certain colours were known to be problematic. For example, vibrant orange is difficult to reproduce if not as a Pantone ink. This was one of the corporate colours for a UK Universities' for which they had found a specific print shop who could produce this colour well.

Another method for managing colour is to use 'simple' colours: the most obvious case of this is when a designer uses 100% C, M, Y or K as no mixing is required; or to a lesser extent when a colour requires mixing just two of the C, M, Y and K inks or toners. But designers also reported a preference for colours that had more clearly proportioned amounts of colours such as C-25% M-50% Y-100%…etc. as opposed to C-17% M-39% Y-41%…etc.. Printing 100% of one colour is more likely to produce consistent results (but will not suit all jobs), as is the use of shades (lightened or darkened versions of the same colour). However, the idea that certain combinations are somehow simpler is more complex: in theory there should be no difference in predictability of results between mixing colours at 25% or 23%, etc. Designers reasoned that they found it easier to envision the colour in print with regular proportions.

Work with the print shop to set the colour values

In situations where customers have very particular colour requirements either they and/or the designers must put in

extra work with the print shop to ensure that the colour requirements can be met. This is done through print device selection (e.g. off-set versus digital), through encouraging customers to pay for Pantone inks and through process colour proofing, and proofing in general. In this way tolerable or desired colours are achieved. For example, a customer with 'very particular' colour requirements (i.e. she wanted very specific colours (like the 'jade' green in Figure 3)) with very little *tolerance* and no budget for Pantone inks was sent to the print shop to work out the precise CMYK mixes that fitted her requirements. In Figure 3 we can see the CMYK process mixes have been added to the image as keys (top left corner). Again we can see here the preference for: 1) choosing and matching colours ***by eye*** – which should not be surprising given that use of colour in design is all about creating a certain *visual effect* (pleasing, shocking, professional…); and 2) for achieving the trust in colour in a simple (to understand), tangible process. By getting the customer to collaborate directly with both the print shop and the design house, good colour can be achieved. However, this is at a somewhat high cost if, for example, the print run was expected to be short.

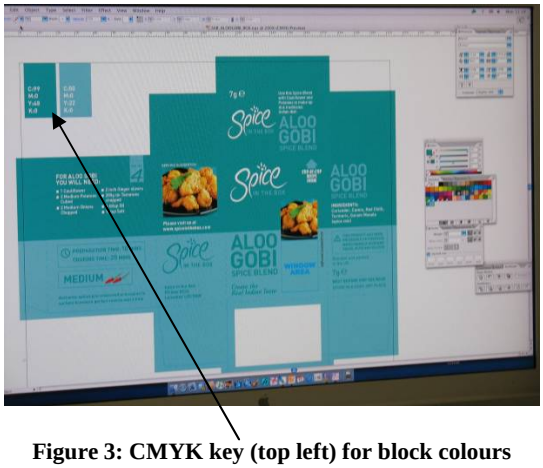

Figure 3: CMYK key (top left) for block colours

The manually adjusted workflow

In some cases printers 'manually' adjust colours in the file, and then print it out to see the effects of their adjustments. Adjustments are frequently made at the Digital Front End (DFE)[1]. Unfortunately the tools at the DFE, such as *emulations* are not easy to use. Emulations are choices for alternative colour spaces (e.g. they *emulate* what the print out would look like if printed on a different print device and/or substrate), and a change from one emulation to another effects all of the colours in a file, often unpredictably, unless the file is colour managed. We found that emulations were frequently used by the print operators for ***aesthetic manipulation***, even though they were not designed for that purpose.

[1] The DFE is the computer that drives the print engine.

One example, an interior design catalogue, came as a ready-to-print file, i.e. not requiring work by the print shop, with a hard copy proof. Contractually, the print shop could have just printed out the entire run. However, they predicted problems so undertook a proofing cycle which duly uncovered differences in colour between the customer's hard copy and the print shop's proof. The first proof was printed using the emulation 'Direct' (which takes the settings straight from the file), but the pink background was considerably lighter than the hardcopy proof see Figure 4. A second proof using 'Euroscale' (a generic default emulation for European printing conditions) produced a closer match to the colours but a less deep and rich black on the front and back covers.

Figure 4: Colour differences between customers

A third proof using 'Euroscale' plus parameter adjustments "Preserve pure colours" and "100% Black TextGraphics" was tried, as an attempt to bypass the transform the Euroscale emulation was applying to the black on the front and back covers. This worked as the covers now printed as rich black, except for a small black tiff logo which remained less black. The contrast was seen as unacceptable, so the print shop decided to prioritize the quality of the images in the catalogue over the richness of the black of the covers, having been forced to choose one over the other.

Compromises like this, between some aspects of colour or image quality, are common when using such methods to adjust the files. This is because they apply changes to the whole document which are difficult to predict, further the results of one emulation will not help to predict the results of applying another. This method is often time consuming and costly, requiring a number of proofs and print shops tend to bear the costs of this proofing work, particularly with ready-to-print files (see [14] for a discussion of why this is so).

Customised spot library

Another approach is to customise the spot colour library on the print device, by creating named spot colours for specific customers and jobs. The spot colour library allows operators to define specific CMYK values for specific named colours within a file. This approach is useful with long-term customers who use the same colours repeatedly

in their jobs, e.g. brand colours, standard templates or covers for a book series.

For example, a library was created for 'Home Seller' (HS), representing a large group of solicitors who printed out window cards, etc. illustrating houses for sale. Each solicitor had their own template, with their own colours, e.g. logo, borders, etc. into which pictures and text about specific properties were inserted by HS (see Figure 5).

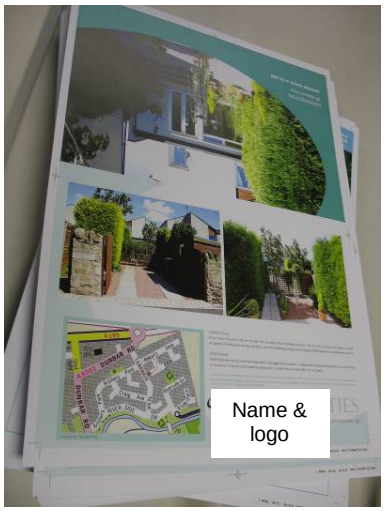

Figure 5: Sample populated template

These jobs were short runs (1-50 copies), submitted as ready-to-print on a daily basis, with a tight turnaround time. The print shop customised their spot colour libraries to suit the different templates, a process which took a couple of months: involving the print shop printing proofs, retuning them to the customer, getting the customers comments, adjusting the spot colours, re-proofing, etc. This provided colour consistency for the template colours, but problems still arose with elements, e.g. photographs, not covered by this process. Any problems had to be addressed with the manual adjustments described above.

Customising the spot-colour library does provide some level of consistency, but requires long-term customers, using predictable colours and ready to go through the customisation process. There is a trade-off between the predictability introduced by customising the spot colour library and being able to use the printer flexibly for whatever colours or graphics a particular job might have.

Summary

The methods described have all been designed to try to reduce, or address, the unpredictability of colour production when moving from digital representation on screen to print and all are collaborative to some extent. No single method provides predictable colour across all print runs and all have disadvantages. Higher costs (time and money) tend to accrue either during set-up or on-the-job; the alternative being limited colour control and more aesthetic compromises. Unfortunately these methods do not fit well into the model for new digital printing markets – which emphasise short-run, on-demand (exact amount, when required) printing with quick turnaround times.

Therefore we conclude that there is currently no single formal method which fits all design situations, but rather a basic set of ad hoc methods and informal workflows that are tailored and deployed according to such features as customer requirements, cost, and designer and printer know-how and relationships. We say this in the full knowledge of the existence of ICC Colour Management, which is aimed exactly at providing a means for formally translating colour between colour spaces and devices and thus achieving good quality colour. We will return to this solution shortly, but first we will examine what our fieldwork has demonstrated about the colour reasoning of designers and printers.

COLOUR REASONING AND THE TECHNOLOGY INFRASTRUCTURE FOR MANAGING COLOUR

Colour reasoning

We can clearly see that the designers and printers know about and attend to the problem of colour consistency across devices, and in particular when moving from screen to print. Let us consider what this 'knowing' consists of. It is a ***practical matter***, ***done by eye, in specific contexts, for particular purposes,*** with all the vagaries of the human perception of colour that that implies. These include the lack of stability of colour perception (e.g. visual context has a great impact on colour perception) and the absence of strong colour memories (e.g. [17]). Examples of knowing about colour and its potential problems include:

- Printers have 'bibles' of customers' regular colours available in the print shop, but they almost never consult these because they were familiar enough with the colours from daily printing that they were confident they could spot differences/problems by eye.
- Practitioners know that certain files are likely to cause problems - such as the interior design catalogue described above, with it's rich strong reds/pinks. In this case, they printed a proof rather than the whole run, even though the job was submitted as ready-to-print, and thus proofing had not been contracted or charged for.
- Practitioners know certain colours are difficult to achieve in print when not using pantone inks, e.g. vibrant orange, so designers may look for a print shop which could produce that colour well and remain with them.
- Printers and designers take for granted that there is a difference between screen and print, and so try to ensure that customers' expectations are realistically set when they view designs on screen.

This knowledge arises in *experience* of dealing with colour on-screen and in-print. Judgements tend to be made by eye and according to notions of 'pleasingness'. For example,

although the designers often match the colour on-screen to that of a swatch book and then encode those figures in the file, they very rarely compare the artefact which returns from the print shop against the chosen swatch to see if the colour matches. Rather they rely on their memory of the colour chosen and the harmony of the results. Only when, as observers interested in the 'problem of colour', we began to directly compare the results returned from the print shop with the initial chosen swatches of colour did we begin to realise the amount of variation which is acceptable.

We do not want to give the impression that designers and printers are not sensitive to colour and image quality, indeed they are. As we have detailed above, designers and printers spend time trying to ensure good, predictable colour and are sensitive to unexpected effects on the print, particularly those that have negative aesthetic affects. For example, printers rapidly scan through piles of print outs checking for and finding colour variations and problems; designers have pointed out to us colour variations in returned designs which they are confident the customer will not notice (as with most situations, what is 'good enough' depends on customer, price, product and so on). So what then causes a print to be unacceptable?

- Direct matching to hard copy proofs showing the printed colours as should be is one obvious time when differences are noticed.
- Another time when colour differences can become noticeable is when variations in hue move it from one colour category to another. For example, a flyer for a coffee shop, with a rich brown background, had been printed on an offset press and was deemed acceptable. Later some leaflets were printed on a digital press, when they were returned, the designer was unhappy with them as the background was 'too burgundy'.
- Also colours appearing as obviously un-natural, e.g. an abnormally red face, or an artificially green landscape make corresponding colour problems noticeable.
- Happenstance is another provoker of noticing – for example if new materials happen to be placed by old materials, differences that may have gone unnoticed are revealed.

An additional point to add to the mix is that finished products may go straight from the print shop to the customer and the designer may never get to see the colour result. In most cases, however, some process of proofing has been carried out earlier, through which agreement has been reached between designer and customer (and printer), setting their expectations for the look of the printed product.

Our findings convey an interesting message: For those involved in the creative design workflow – customers, designers and printers – ***trust in colour*** is about a number of things that do not relate to the scientific specification of that colour. Instead they relate to the nature of the processes used to view, match, encode and 'save' colour; to the role of standard guides in these processes and to the working relationships of the people involved. If the process is simple to grasp and involves visual matching and looking up values to encode, it is tangible and trust follows. If the people involved help you produce products you like aesthetically, trust follows. When trust is in place, it encourages a wider tolerance in the colour of the product and also means that graphic designers may see no need to follow up on the printed results of their designs (certainly not to test their colour) if the customer is happy. Of course, as we have noted, there are conspicuous cases where the product is seen as being the wrong colour, but interestingly this does not set those involved in the industry on the path to systematic checking of colour. Such an approach would reveal previously acceptable products to be off-colour and it seems to be the case that variance is tolerated if undiscovered (or not obviously noticeable)! Indeed, only in exceptional cases would the systematic checking of colours returned, against colours chosen, be merited. Designers (and their customers) make judgements on the basis of the look of the returned product; does it look nice, does it make the impact they had intended, and so on? That is, is it 'good enough'? Unfortunately, this creates a set of complications concerning possible technical solutions since the problem is also clearly social and organisational (e.g. signing off designs, proofs, etc. represents acceptance of amongst other things, colour, often somewhat irrespective of the precision of a colour definition).

The technical infrastructure

For the purposes of developing technology, the problem has been modelled as one of colour consistency in a technical sense – that is of trying to get consistent colour reproduction across devices. ICC Colour Management is a technical infrastructure that has been designed to achieve colour constancy (to the extent it can be achieved, keeping in mind the different device gamuts). It was designed to create as good a match between devices as possible and to automate the process of transferring colour information, by attaching colour information to the file itself, so that the print machine can automatically determine the 'correct' colours. The aim of using ICC CM is that what is shown on screen will accurately represent what will be printed out. Basically ICC CM works by attaching a profile to a file indicating which colour space that file was created in. When the file is transferred between devices a transform is applied that translates the device dependant colour values into a device independent colour space and then this is transformed into the colour space of the device that the object will be printed on. It is important to understand that *some form of colour management must take place* for colours to be produced on screen and to be translated between applications and devices. That is, CM is taking place in the background whether the designers and printers are aware of it and conforming to its protocols or not. What correct use of the ICC CM system aims for is the consistent

representation of colours across devices, so that what is seen on screen is close to what will be printed.

However, as mentioned in the introduction, colour management is rarely used as intended. The CM infrastructure is accessed by a number of applications – design tools, print engines and so on – as part of the document design workflow. Each of these applications has its own interface, where choices have to be made about the interaction between that application and the infrastructure. These choices have a consequent effect on the appearance of the document being designed. Currently, to make the right choices at the interfaces the various actors in the document design workflow *need to understand how the technical infrastructure works*. Just what the optimal set of choices would be for a document depends on the sources of material (e.g. photographs, vector graphics, 'block' colours) and the particular desired aesthetic output in print (or elsewhere). Furthermore, implementation of ICC CM requires a strict, coordinated and knowledgeable adherence to a set of procedures and protocols by people across a document's entire lifecycle, from conception to production. These procedures include things like the regular calibration of all devices, and the correct CM choices at every step of the design process.

The socio-technical nature of the problem

ICC CM is what could be described as a *technically correct* solution to the problem of colour production. However, it does not take into account the *socio-technical nature* of the problem. Our fieldwork clearly shows that the production of colour is a socio-technical matter. Designers and print shops employ a range of mundane, collaborative practices designed to help them navigate around the problem of producing predictable, pleasing colour. These practices go on alongside the technical management of colour and the two sets of systems – the practical and the technical – interact in ways which are non-predictable for the designers and print shops. Sometimes the two systems may work together to produce good results, at other times they may clash, producing unexpected effects. Either way, because of the complexity of the interactions between the various applications, devices and choices (made more or less explicitly along the way), the effects are not easy to explain, except perhaps by colour scientists.

Our analysis has suggested three possible areas in which ICC CM diverges from peoples' practical methods of creating and producing colour.

1/ Aiming for consistent versus acceptable, good enough colour. ICC Colour Management works on a notion of consistent colour reproduction across devices. The notion of *consistency* in its technical sense means translating the integers representing a colour on one device and its colour space into as close a mathematical representation as possible on another device and its colour space. Considering the social practices around the management of colour, we see that certainly notions of consistency are important – across different runs and so on, even from screen to print. However, quite wide variations in colour can be acceptable (indeed not always noticed), whereas at other times variations can be clearly noticed. One question then is what is noticeably good/bad colour? When one looks at the graphic design-print workflow one can begin to see how such noticings occur. The notion of *tolerance* is situated, in the design, the product and the intended and produced colour (e.g. tolerance is likely to be lower where colours cross a perceived colour boundary such as from brown to burgundy, but it is also very much worked up in an understanding of the customer and what they want). Judgements on colour are *circumstantial* – that is not only are they situated according the characteristics of the job, the customer and so on, but to a large extent they also occur because they *happen* to be noticed. They arise out of particular circumstances e.g. materials happen to be side by side, the colour varies across some colour boundary, the image does not look harmonious etc. What constitutes acceptable colour is a *collaborative achievement* – designers and customers come to agreements around the screen, the swatch book and printed proofs. It is not necessary for the colours to be mathematically the same for agreement to be reached. For example, when working with Pantone swatches, in the mode where a swatch is chosen to relate to the colour on screen designers do this in a more or less approximate fashion. The screen is but a guide to selecting a good colour. Designers work with a belief in a necessary difference between screen and print, so this does not really bother them.

Also, even under optimal conditions, CM cannot alter the fact that colours are produced in different ways, giving different visual effects and that different devices produce different ranges of colour. It seems that it is not enough to have a purely technical instantiation of colour consistency. Practitioners want good enough colour, and therefore are concerned with such questions as will this be harmonious, are there going to be any colours that print very badly, do I stand any chance of getting the yellow I want, or which sets of colours print well on digital? This is situationally and circumstantially determined, and is a visual and practical phenomenon rather than an abstract, mathematical one.

2/ Complex, numerical versus practical tangible, visual understanding of colour. ICC colour management is a technically complex system, requiring an understanding of colour science – the *mathematics of colour* – yet in their everyday work designers and printers build up *practical, tangible, visual understandings of colour*. That is, colour as visually experienced and manipulated, not colour as numerically represented and transformed - and the methods they use to address the problem of colour production reflect this. Understanding and putting in practice colour management would require learning about colour spaces and so on, which stands wholly outside of their practical, visual approach to colour. Unless one is a colour scientist

thinking about colour in an abstract 'space' is incredibly difficult to do.

3/ Automatic and end-to-end versus collaborative and flexible colour management. Whereas the methods of designers and printers for achieving colour across screen and print workflows are collaborative, colour management aims to automate the process. If it was used correctly, in an ideal state, all communication between print shops and their customers could be achieved via the encoding of files. However, such a situation seems highly unlikely and in reality any creative design colour managed workflow would take a lot of close collaborative work to design, deploy and enforce. At the moment it is not used and print shops and designers are left to create their own ad hoc practices using the tools and technologies available and *understandable* to them.

DISCUSSION

In this paper we argue that colour production needs to be seen as a socio-technical problem for the purposes of designing solutions. What complicates the situation is that it is of course necessary to have mathematical representations of colour and transforms between them for colour to be produced on different devices and for predictability or colour consistency to be achieved. We are not then arguing that colour management is not necessary, rather that the system as it is, while it might work technically – in theory – does not get the opportunity to do so because it does not work socially and organisationally. This is fundamentally an issue of its *instantiation, translation* and *communication* in the settings and menus of devices and applications which require the user to understand the abstract workings of the infrastructure to be able to make the right choices. Thus one may draw a parallel with many other CSCW studies, which point out that the technology which was designed to simplify workflow instead might be considered to complicate it, e.g. [2] [5]. Rectifying this however is not a simple problem, we are not talking here of for example a workflow system, modelling some particular line of work, rather we are talking about an infrastructure that goes on working whether one is using it correctly or not. It assumes that the workflows interacting with it are colour managed, but in fact they are not, and thus unexpected results can occur.

The colour management solution was engineered to solve the problem of colour reproduction. However, that problem was modelled purely as a technical problem – how to communicate colour information between machines. No real understanding of the socio-technical settings into which it would be put was considered nor the lived reality of practitioner understandings and workings with colour. The result is an infrastructure on the device side which models colours through numerical values and transformations to these values. But this is very far from the way that people reason about and manage colour, which consists of tangible, visual understandings of and situated, circumstantial judgements on colour. Practices are collaborative and pragmatic agreements are reached on acceptable, good enough colour. Even where Pantone inks are used, e.g. for brand colours where agreed upon numbers are assigned to a colour to reproduce it, in the design stage the Pantone is not chosen because it has a specific numerical value, rather it is chosen because for whatever set of social reasons the colour looks right and this is then represented by the numbers. The numerical encoding of colour (which is needed to represent colour by devices) *stands wholly outside of practitioners circumstantial and situated practices of choosing, manipulating and correcting colour*. The result is that at the moment we have two different and apparently incompatible systems with two different ways of modelling colour, which unfortunately interact in unpredictable ways.

DESIGN IMPLICATIONS

There is not, as yet, a simple solution. We have two different systems which do not fit together, but we cannot just throw out the technical system and start again as, like it or not, digital devices must use a mathematical model of colour. However, just as the problem of colour production is a socio-technical one so prospective solutions must take into consideration the social as well as the technical aspects of the problem. This, as we indicated earlier is a familiar issue to CSCW – the need for design to orient not just to the technical nature of the problem but also to the social nature of use of that technology. In the process of producing colour, information is communicated between people and devices and we therefore need them to be working together on some level, either through a common understanding or if that is not possible through mediation between the two systems.

Design initiatives could do a number of things:

1/ Align the people to the technology, so that the people using the technology, the designers and the print shops could make the right choices throughout the process, for example, by educating people in colour. However, it is doubtful that there is a rush of people in design and printing waiting to be educated, and as we have stated, a large part of the problem is the sheer complexity of the subject.

2/ Align the technology to the people, providing better user interfaces, for example, by designing appropriate default settings and workflows for software. However, building and maintaining custom workflows would be expensive, as these would vary depending on different document characteristics such as which 'elements' they comprise, and would not eliminate all colour problems. That is, because of the sheer variance in the possibilities for colour management, and since there is not a standard set of resources and requirements, building a default workflow that applies well across situations is very difficult. Instead, numerous workflows would need to be designed.

3/ Mediate between the technical system and the people using it. Design directions therefore could lie in trying to

create solutions which 1) support and facilitate the collaborative features of the work through a language adapted to the tangible and visual understanding of colour 2) try to bridge the gap between technical and visual representations of colour, and 3) enable a more flexible workflow not necessitating strict end-to-end colour management but allowing it to be introduced later on in the process or 'recovered'.

CONCLUSION

We have described the problem of producing colour across the screen-print workflows, indicating how currently colour production is a collaborative achievement by designers and printers, often across organisational boundaries. We have sought to show how the colour problem, rather than being a purely technical problem requiring a purely technical solution, needs to be viewed as a socio-technical problem: this opens the door for socio-technical solutions. The current solution does not support the work, being highly complex, non-robust and aiming at automation and is rarely used as intended. Certainly one solution might be to look at ways of simplifying, explicating and so on ICC Colour Management technology. However, we believe that there is space for new socio-technical technologies to be designed. We cannot get away from the representation of colour by devices as a complex mathematical language, which needs to be manipulated by transforms. However, this seems far from the practical, visual working with colour of designers and printers. Therefore we envision and are now actively pursuing a solution (along the lines of 3 above) that *mediates* both between (1) designers and print shops across the organisational boundary at the point of file submission, and (2) between the practical colour work and understandings of practitioners and the underlying infrastructure, thus enabling a flexible collaborative workflow. We will report on this work in due course.

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