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CAN COMPUTER GRAPHIC SYSTEM BE USED TO INFORM DESIGNERS ABOUT INCLUSIVITY?

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1. Introduction

During the last decades many methods have been developed to inform designers about accessibility and usability problems in new design concepts. Most recently, as the elderly population has been increasing, other efforts have been made to prevent problems caused by losses of capability that result from the ageing process. For instance, there are mechanisms that measures the exclusion caused by certain tasks to enable product developers to estimate how many people will not be able to use their product, service or interface.
Despite the diversity of currently available methods and the value of the information provided by them, the majority is underused in industrial context. As part of an on-going research that investigates effective ways to supply designers with knowledge about accessibility and inclusion, this paper analyses an alternative way to advise designers about the features of a new concept design. Computer graphic system was identified as a possible accessibility and inclusivity information medium. However, the use of three dimensional (3D) digital modelling and graphic software very early in design activity is not clear. In fact, most cited literature in design activity acknowledges the use of computer graphics systems only at advanced stages of the design process.
The paper presented here analyses the design activity to understand the use of 3D digital modelling and graphic software in the early stages of design process in industrial context. In addition, it examines how the use of such tools differs among industrial design domains. The outcomes elucidate how computer graphic systems could be used to inform designers about accessibility and inclusion.

2. Available techniques to evaluate accessibility and usability in design process

A previous study explored and detailed the advantages and disadvantages of a range of tools and techniques currently available to evaluate accessibility and inclusivity [Zitkus et al. 2011]. Although the techniques are diverse (participatory design, user trials, simulation suits, digital human modelling, virtual resources and others), the study indicates that they are underused in industrial context mainly due to problems related to integration into design process and the outcomes of the assessment.

2.1 User participation

Participatory design and user trials, for instance, are well known design evaluation methods that enable designers to understand user's need and develop empathy to them. The value of these techniques is proved to be high as they fruitfully highlight accessibility and usability problems that designers would not realise by their own assessment. However, in industrial context user-related design problems are commonly measured against possible market loss. In this case, the participants should be selected to represent a spectrum of age and capabilities to enhance the resulting accessibility and usability data.

On the one hand, sample selection and size positively enhance an estimation of the exclusion that product features may cause. On the other hand, the time required to select and recruit a representative sample, added to the time for organise and run user trials, negatively affect the design process. The more the time a technique consumes, the less probable is its adoption by the industry. Moreover, the integration of users to design process is also challenged by confidentiality problems and ethical concerns in the case of recruiting elderly and disabled users.

2.2 Simulation

There are two different approaches in which simulation is used to evaluate accessibility and usability of new design concept: simulation suits and virtual simulations.
The first involves wearing suits with pads attached restricting movements and fogged spectacles that limit the vision. By performing tasks while using these apparatus designers can experience some of the restrictions imposed by certain impairments, which is an inspiring activity. However, designers find it difficult to prioritise accessibility and usability problems that most reflect user's needs. The outcomes from the simulation therefore do not guide the designers to concentrate on more recurrent accessibility or usability problems. The incompatibility of the results with the needs of the designers may hinder the adoption of simulation suits in industrial context.
The same happens with virtual simulation methods in which digital human modelling (or avatars) is used to emulate different people performing tasks. The outcomes from virtual task simulation are dependent on designers' knowledge and their assumptions. As a result, designers find it difficult to prioritize problems and address the user's needs, including the disabled and the elderly.

2.3 An alternative way to advise designers

The techniques mentioned above either are difficult to integrate to industrial design process or rely on designers' knowledge of the task. There are cases, however, where it is not necessary to perform tasks to find design problems. In other words, there are features in everyday products that demand physical, perceptual and cognitive skills beyond the capabilities of a wide range of users. For example, there are products or interfaces in wich the text size is too small to be legible or texts that are written in certain colours that the background- foreground colour contrast is too low to be visible. These features unable people with visibility problems to see and use everyday interfaces. In addition, there are also buttons that are too hard to press, or knobs and switches that are too small to turn and thus, they would hinder individuals with dexterity problems to use the product.
All the above examples are common problems which exclude people with disabilities from using everyday products. This is the reason that designers should be advised about design features in their new concepts very early in the design process, when changes are affordable and easily done. This could possibly be done by software evaluations through interactive information, following procedures well disseminated among engineering designers. For instance, in industrial context, software analysis have been used for FEM (Finite Element Method), mould flow, stress strain and other evaluations. However, the use of computer graphic system by product, packaging and graphic designers in the early stage of the project is not widely discussed. The role of computer graphic system in the industrial design practice is not clear, neither is clear the sort of inclusive design and accessibility information that could be provided to designers that is cognisant of their work routine.
The next sessions review some of the literature that focuses on the design activity in the creative phase – the conceptual stage - to elucidate the role of computer graphic systems.

3. How is the use of computer graphic system framed in past studies?

One of the most influential books about the design activity is Lawson's work [Lawson 1997] carried out with expert architects more than 30 years ago. In this book the author analysed the design activity and the designer's behaviour.
Regarding the design activity, Lawson explained that sketching is the base of designing. He analysed 'drawing' or 'sketching' as a thinking process and communication media, though he recognised some of the limits of sketches, such as misleading appearance and the difficult of accurately presenting the way the idea would work.

In the 1997 edition of Lawson's book there is a chapter that covers the role of Computer Aided Design (CAD) in the design activity. In this chapter the author stated that in reality CAD should stand for computer-aided drawing instead of computer-aided design [Lawson 1997 pp.286].
Lawson's views about CAD are similar to other researchers during the 1990s, who did not conceive CAD as a tool collaborating to the generation of ideas. For instance, [Roy 1993] wrote about the design activity and the use of CAD in new product development. According to the cases analysed by Roy in industrial innovative design, CAD was used to evaluate and improve a defined idea, marking the change of the creative design process towards the manufacturing.
Similarly, the compiled papers edited by [Cross et al. 1996] illustrate the coherence of Lawson's view at that time. The papers report on the experiment carried out by the Delft University of Technology with collaboration of Xerox PARC and the Design Research Centre of Stanford University. In the study the participants were supplied with "*table and chairs, drawing pads, pens and pencils and whiteboard"*, which were meant to be the set of tools related to the design activity in the conceptual stage (pp.184). The only reference to CAD was done in a chapter that stated that the participant designers "*never really got into the detail information refinement that is the focus of most current design aids such CAD"* (pp. 171). However, no further mention to CAD was made in the other 20 chapters of the book to report the absence of computer graphic system as a medium to create or to represent ideas.
Lawson's argument extended the attempts to make CAD to work as solution generator, which, according to the author, have proved not being as creative as human designers. The author added that the creation of a variety of solutions to support designers to comply with requirements does not work according to design activity and, therefore, are not aiding design.

3.1 Is computer aiding design?

Since Lawson's seminal book, many changes have happened in the domain of computer graphic systems, including CAD. Although a number of research focused on aiding design through computer interfaces were based on 1970s ideas, such as those highlighted by [Alexander et al 1976], they became practical approaches only at the end of 1990s.
Pattern language [Alexander et al. 1976], which consists of listing the drivers of architecture design, is the foundation of some current work being developed in parametric CAD. [Duarte 2005], for example, developed a natural language processing system that compiles the inputted aspects to be considered in a given project to automatically generate possible solutions.
Similarly, [Visser 1996] proposed the 'case-based' design as a way to enhance computer-aided-design. The 'case-based' approach consists in the development of knowledge-based systems that are based on the 'design-reuse' approach used by many designers while creating a new concept. The 'design-reuse' is the recurrence of previous ideas that are continuously modified until reach the desired concept. In this case, new concepts are guided by patterns processing systems.
Natural language processing systems and property of patterns processing systems seem to be well developed in some design fields. In engineering design, for instance, where manufacturing issues are mandatory to new concept design, there are studies, such as those of [Rao et al. 1999] and [Bandini and Sartori 2006], that show the progress of automated design.
Along the years, CAD software has facilitated the integration of two dimensional (2D) drawings with three dimensional (3D) models. Additionally, photo realistic images and 3D renderings were enhanced with high resolutions and improvements of vector graphics [Shirley et al. 2009]. There are also cases in which expert systems have been used to redefine the 2D digital sketches into 3D models, as shown by [Olsen et al. 2009].
Although computer graphic systems have been explored in academic research, the role that they play in the conceptual phase of design process in industrial context is an aspect undermined in past research. Additionally, the variations of different design domains are important aspects to be considered. According to [Clarkson and Eckert 2005] comparative studies have shown that the process of design is similar in many ways, though the approach and emphasis of each design activity differs among professions. This possibly modify the way computer graphic system are used and the stage of the process in which they are used.

4. Investigating design activity in industrial context

This session reports a study towards clarifying the way industrial designers work, as well as 'how and when in the process' computer graphic systems are used. The outcomes were meant to clarify the ways in with effective information about accessibility and inclusivity could be supplied to designers while they are creating new concepts.
A study was carried out at two British design consultancies, involving 11 industrial designers (product, packaging and graphic designer with an average of 10 years experience). The methods selected to the study combined observations with interviews. Designers were presented with the findings from the data analysis and feedback was received to verify the types of actions taken during design activity.
Care was taken to ensure that the observation was highly descriptive in order to identify the activities that took place and, mainly, to recognise the meaning of the actions, interactions, behaviours and language, according to the participants. The focus of the study in one of the design consultancies was to observe designers at work (seven designers were observed, two of which were interviewed) whilst in the other the study was focused on interviews (four designers were interviewed).
The data gathered followed a structured analysis proposed in grounded theory [Corbin and Strauss, 1990]. The interviews transcripts were added to observation data and then analysed, interpreted and classified into categories. The categories and sub-categories were separated and organised to structure the major themes under analysis. The transcript's extracts or 'chunks' were the sources to create, replace or increment the categories linked to the themes, which were posteriorly represented in diagrams. These categories were arranged according to the importance given to the concept and its connection to other sub-categories. The diagrams generated from analysis where presented to the designers and feedback was gathered, which was also categorised and analysed.
As this study is part of a research in progress, new data has been constantly added to old one and both are constantly scrutinised, interpreted and verified.

4.1 Designing new concepts

The outcomes from observations and interviews elucidate a scenario in which industrial designers work. The interviews' responses and the aspects observed in the study describes a similar process that happens in the conceptual phase: designers normally generate a range of concepts and then present these ideas to the client (who owns the final product). After receiving the client's direction they narrow down the range of ideas and then refine them before presenting to the client again.

4.1.1 The initial steps in new ideas generation process

As mentioned by the participants, in order to deal with the range of specifications that the project has, at the beginning designers roughly sketch or map their ideas to memorise a range of possibilities.
"(designers started with a) *rush of ideas and potential ways to go and ensure that all of them are captured as early as possible. That's what I tend to sketch and I do rough sketches of different styles as much as it seems to serve to my memory*." (16:27 – 06)
"*There is something I've just started sketching up in CAD it is very basic, very crude*" (07:07 – 11)

4.1.2 From rough sketches to more elaborated ideas

During this initial stage industrial designers have to elaborate their ideas before presenting them to clients. Designers then have to select the right way to present them, which normally is a choice among sketch, 3D digital model and mock-up.
The selection varies according to aspects pointed by some designers, such as the client understanding of sketches or the stage of the process.
"*But sometimes people need 3D format to actually visualise it.*" (08:51 - 01);
"*Rather than having to explain this things on sketches, we got a quite of technical solution, it would be very hard. Even though we understand what the sketch is, sometime people don't, they have much more engaging response by seeing and touching, and even if it is not a perfect finished model, but something close*." (21:04 – 06)

If the refer to the initial stages, they should not look too polished or too detailed. They should emphasise the stage of the project in which new concepts were developed.
"(the designers have to be) *quite restricted in really early stages, and if you just got a sketch, what is quite obvious that it is rough, and that they can still afford to change it. Where as if it looks too polish or too final too early on that can be negative in many times... If you present someone something that is done in a computer if it is 3D CAD, and they think that it is something that you normally get a long way down in the design process, they would look at imprecision in the design. They would think they invested more money in that stage.*" (08:21 - 01)
Frequently, designers present the first range of ideas in a sketch format. This, however, does not necessarily mean that the sketch was done on paper. As pointed by four designers who were interviewed, the sketch could be done on tablet by using software such as Photoshop and Illustrator. The sketch can also be done over a photo taken of a mock-up, or over a 'block CAD'. 'Block CAD' or 'not proper CAD' should be understood as those CAD that are not detailed enough or those that are not prepared for manufacturing. They are CAD model that only shows the appearance of the concept.
Nevertheless, it was also mentioned that the way of presenting the first series of concepts is also driven by the designer's preference.

4.1.3 From more elaborated ideas to final proposals

The interviews brought to light that product designers use 3D digital modelling tools, if not before, from the stage where the ideas will be narrowed down to few proposals. Software like SolidWorks and Pro-Engineer are largerly used at this stage. At this point, photorealistic renderings, generally of three chosen concepts are generated (and sometimes enhanced by Photoshop or Illustrator) and presented back to the client.
"*We present a kind of power CAD, and they will normally be rendered up, kind of almost a photorealistic."* (07:40 - 04)
All designers interviewed in this study showed their concern about the way ideas are presented. The idea's presentation serves to communicate to the client, independent of the format that they have (sketches, 3D digital model or mock-up). The designer's concern is that the presentations have to clearly communicate to comply with their purpose.
"*It is very important, we could come up with a good design but if it is poorly presented it could fall flat in his face, if you are client, you can imagine, if we come with great design and did some random sketches and brought it all in a piece of paper it can loose its impact and not impress*."(18:10 - 03)
The interviewees stated that it is through the presentation that designers communicate the features of the product, such as the aesthetical, technical and mechanical solutions. The presentation communicates potential directions and engage with clients to get their opinion and to receive their feedback.
"*When people can actually see a possible feature that is when we can start to get some feedback as well about what is right and wrong in that… The fact that it is in that* (photorealistic) *format allows the client to engage easily, because they can see a product, they can talk about it easily, because they got less to trying to make up the gaps.*" (14:45 - 02)

4.1.4 Differences between design domains

There is also some variation according to the design field. For example, in packaging design mock-ups are created since the very beginning of the project without using 3D modelling software, but other computer graphic software like Corel Draw.
"*It tends to be a combination with me. The way I work I tend to quite quickly progress to what other people would think is quite technical samples. So, I would draw up here* (pointing the computer) *and would go straight cutting them up* (in the laser cutter), *presenting them as a series of white models as we call, 3D sketches, almost*." (17:54 – 06)
" *Rather than having to explain this things on sketches we got a quite of technical solution, it would be very hard, even though we understand what the sketch is, sometime people don't, they have much more engaging response by seeing and touching, and even if it is not a perfect finished model, but something close.*" (21:04 – 06)

"*I don't use 3D software very much, but we actually make models and that sort of things, like quick mock-ups to show the clients to get them to see how it looks, where the text is, if it is too big or small, and things like that.*" (06:10 – 05)
The observations confirmed the fact that computer graphic systems are widely employed. During the time the observation was carried out, product designers were drawing or modelling in CAD or using other computer graphic tools. In some cases, 3D digital modelling is one of the most time-consuming activities of product designers.
"*3D modelling is probably one of the areas I spend most of my time doing.*" (03:27 – 08)
In graphic design, it was also observed designers using 2D software while the observation was carried out. The type of software was later confirmed in the interviews:
"I think most of the designers agencies use Illustrator or Photoshop…" (07:23 – 05)
In this study it was not observed designers sketching on paper, rendering in CAD or making a mock-up to present to the client. The designers working in CAD were either detailing a 2D drawing or changing curves in a 3D model to change the model surface. Packaging and graphic designers were respectively drawing the package's cut-out in Corel Draw and creating new concepts in Illustrator. Therefore, the final development of a presentation was not observed.

5. Comparison of the use of computer graphic systems with previous research

The data gathered with designers clearly underline the use of 3D modelling and graphic software in the design activity. The designers' responses and the observation support a clear understanding about the way ideas are generated, elaborated and presented.

5.1 Designing within computer graphics

Graphic and 3D digital modelling software have been used to improve the way the idea is presented. The use of 3D renderings, photorealistic images and animation guide clients or other stakeholders of the project to the correct understanding of new design concepts. As mentioned by one interviewee, photorealistic images help to engage clients as they can easily realize new concept designs and do not have to guess what has been represented (session 4.1.3). Additionally, most of CAD software has properties that allow further detailing of the new idea that can be applied towards the way it works, avoiding misunderstandings. Consequently, the design constraints pointed by Lawson (1997) related to the 'misleading appearance' that hand sketches could have and the difficult of presenting the way the idea would work, are not significant issues if the resources presented in computer graphics are used. In these cases, CAD can be considered as an decisive factor that can change the client understanding of new design concept.
Although the study did not highlight the use of parametric CAD as multiple solutions generator, it was highlighthed the use of CAD software and free modelling sources. CAD is very much integrated to the design activity. Hence, the criticism from [Lawson 1997] about CAD as solution generator unaware of the design activity seems to not correspond to the growing use of parametric CAD.

5.2 When in design process are computer graphic systems inserted?

According to the study, in industrial context, designers rely on computer graphic systems since the very beginning of the project. Ideas are generated and then elaborated in harmony with the stage of the process. As mentioned, ideas presented in sketch style can be produced within digital resources to intentionally represent the stage of the process.
According to the study some product designers start their creative process in CAD straightaway. The use of CAD was confirmed during the observation when designers were drawing or modelling. Even in the case of packaging design in which mock-ups are cheaper and quicker to engage clients, normally the process involves drawing the cut-out cardboard pack in a computer graphic tool and from there sending it to a laser cutter. Similarlly, the process of starting designing within computer graphic tools was observed while graphic designers were creating new concepts. In this way, it seems that even initial ideas generated by product, packaging and graphic designers are likely produced within computer graphic systems.

By using computer graphic systems designers are more likely to clearly delivery their ideas to clients. This enables the designers to stablish an effective communication process, which is one of the major concerns designers have, regardless their design domain.
The adoption of computer graphic tools as means to designing and enhancing the design is a fact that diverges from the idea of [Lawson 1997] in which computer graphic tools were not recognised as part of the design activity in the conceptual phase. Similarly, the laboratory experiment carried out by [Cross et al. 1996] does not represent the way designers currently work in the conceptual phase. Consequently, by ignoring the influence that computer graphic systems exert in design practice, the studies of [Lawson 1997] and [Cross et al. 1996] are not a complete portrait of the current state of design activity.

6. Benefits of understanding the role of computer graphics in industrial context

The results clarified that computer graphic systems are established tools in the industrial design practice. As a result, these tools can be used to inform designers about accessibility and inclusion of some features while these features are beign designed in new concepts. This could possibly be done by software evaluations through interactive information.
An alternative way to advise designers about accessibility and inclusivity is shown on figure 1. The figure illustrates how designers could be provided with inclusity information about text legibility whilst a new concept is being designed.

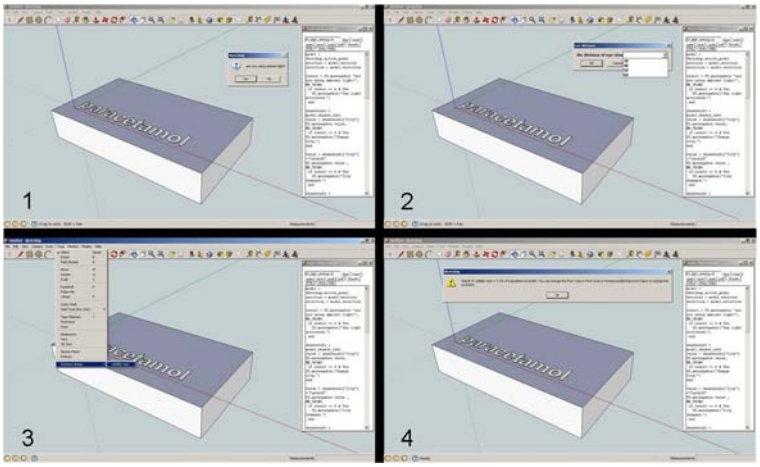

Figure 1. A computer graphic automate advice system to inform designers about inclusivity

The proposed automate advisor would analyse the input data automatically generated while designers are creating ideas within computer graphic system. Designers would interactively provide additional information, for example the 'reading distance' for legibility assessment. The outcomes would therefore vary according to the values entred in the system.
The design under development could continuously be assessed every time changes occur in the design features. It could indicate early in the design process accessibility issues related to physical aspects of new designs. These evaluations would happen with minimal impact into the process.
Alternative ways to inform designers and the type of information to be provided to designers are the topics under investigation in this ongoing research (Zitkus et al, 2012). The type of information has to be cognisant of the design practice, whether it is product, packaging or graphic design. To support designers effectively, further research has been carried out to adequate the provision of statistical data about inclusion through 3D or 2D graphic software packages.

7. Conclusion

Improvements in computer graphic systems indicate that they can actually act as computer aiding design in the conceptual phase of the design process. The outcomes highlight that CAD and other graphic design tools are totally integrated to the design activity among different design domains. Ideas

generated during the conceptual phase are likely produced within computer graphic systems as they support designers to comply with the main role of presentations, which is to clearly communicate ideas to clients.
Inclusive design would be benefited from computer graphic systems as the latter could be used as a platform to advise designers about design features in their new concepts. The use of input data stored on computer graphic systems would assist the assessments and make them less dependent of designers' knowledge of the task. Designers would be informed very early in the industrial design process when changes are affordable and easily done, which would facilitate the integration with the process. This would support designers to create and develop more inclusive new concept designs.

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