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DRAWING STANDARDS FOR EARLY DESIGN: WHERE DO WE STAND?

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ABSTRACT
Despite the availability of Computer-Aided Design (CAD) systems, *paper*-based sketching is still widely used during conceptual design due to its efficiency in externalizing form solutions. The main reason attributed to this is that the user-interface of most CAD systems follows the WIMP (Windows, Icons, Menus and Pointing device) paradigm which does not support freehand form sketching as input on normal paper. Yet CAD systems still offer advantages for early form design such as three-dimensional (3D) model visualization. Thus designers would greatly benefit if the advantages of manual sketching are combined with those of CAD. However, due to various factors, such as the idiosyncratic style of sketching, computer processing of hand-made sketches becomes difficult. At the same time, although drawing standards are available for detail design, standards for early form sketching are unavailable. To address the above issues, this paper reports on-going research aimed at providing a drawing standard to seamlessly link early form sketching on paper with 3D modelling technology. The paper provides an overall picture of the state-of-the-art approaches to early form sketching. A drawing standard has been developed to address the identified deficiencies of current approaches. The developed standard specifies what is required both for the *process* of drawing and the representation of form in the resulting drawing, i.e. the *early form sketch*. Besides from providing 3D models directly from paper sketches, such a standard has been found useful for collaborative design. Evaluation results indicate what aspects of the proposed drawing standard require improvements.

Keywords: Conceptual design, early form design, computer-aided sketching, design collaboration

1 INTRODUCTION
Although conceptual design is the most critical stage in the design process [1], most of the commercially available computer-based design tools, such as CAD, are suitable for the later stages [2]. The inprecisely defined concepts generated in the preliminary design stages on the one hand and the well-defined models required by computer-based engineering tools on the other hand, complicate the early incorporation of such tools in conceptual design [3]. In relation to this, the user-interface (UI) of most CAD systems, more specifically of *Computer-Aided Geometric Modelling* (CAGM) systems follows the WIMP (Window, Icon, Menu, and Pointing device) paradigm [4]. Several commands and the rigid interaction associated with this type of UI tend to interfere with the designer's mind and disturb creativity [5]. For this reason, designers continue to rely mostly on paper-and-pencil sketching in conceptual design [5].
In spite of the aforementioned limitations, CAGM still holds strengths for supporting early concept generation [6], such as visualization of 3D models. Manipulating a 3D model is better than a sketch for visualisation purposes, as it can be viewed from multiple viewpoints. 3D models are in fact the most concrete and spatially specific means for visually supporting the development of design ideas [7].
To bridge the chasm between sketching and CAGM, and hence to combine the benefits of both, *computer-aided sketching* (CAS) support has been developed by many researchers [3], [4], [8] [9] and [10]. CAS support is beneficial to rapidly visualize an evolving concept which otherwise may be very hard to accomplish with just a sketch drawn on a two-dimensional (2D) medium. In [11] it is argued

that the easy availability of 3D geometric models generated from sketches of automotive products can assist further the development of concepts. Additionally, these models can improve the communication to and evaluation of concepts by other product development stakeholders. Reduction of many repetitive tasks and increased design creativity are the two reasons mentioned in [12] to justify the need of developing CAS support. The informality of freehand sketching on the one hand and the formality required by computers on the other hand, necessitates a drawing standard in order to provide such a support.

The word 'drawing' can be used either as a verb or as a noun. When used as a verb it refers to the *process* of drawing, whilst as a noun it refers to the resulting *output drawing* (Figure 1). This introduces two related, yet different levels of specifying a drawing standard for early form sketching:

1. drawing (as the *process*) - relates to what type of sketching medium (e.g. paper, digitizing tablets etc.), markers (e.g. pencil, stylus etc.) and drawing stages (e.g. using light construction lines followed by darker lines) one employs to draw;
2. drawing (as the *noun*) - relates to the representation of the actual form geometry in the sketch, such as by using either 2D views (e.g. sections) or 3D projections (e.g. perspective) or both.

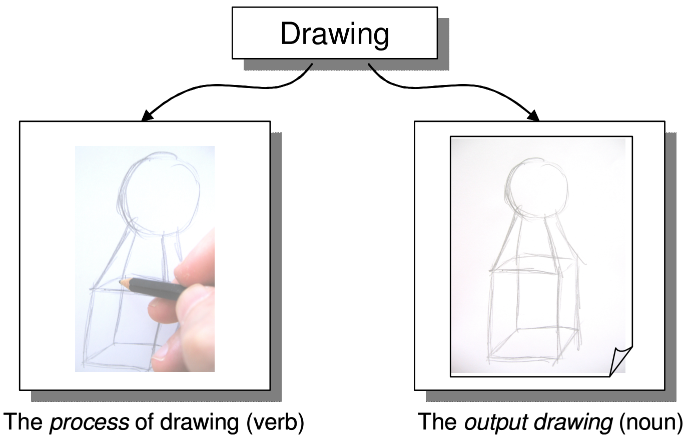


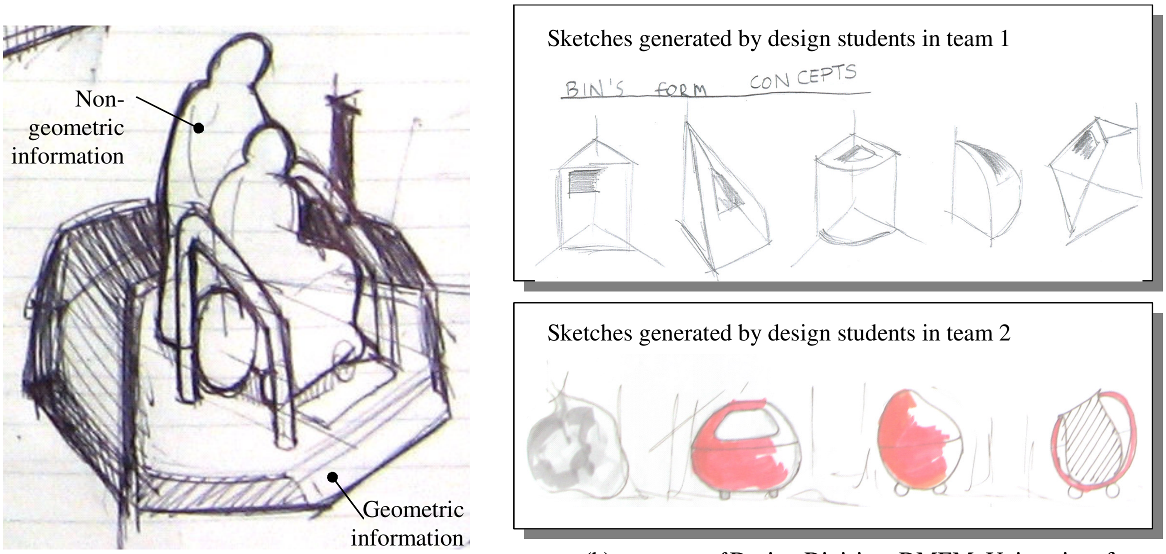
Figure 1. Drawing as the 'process' vs. drawing as the 'noun'

The next section justifies why a drawing standard for early form design must specify the requirements for the above two levels.

2 COMPUTER PROCESSING OF EARLY FORM SKETCHES

One of the intrinsic characteristics of freehand sketches is the co-existence of geometric and non-geometric information. Difficulties arise to separate, by a computer, these types of information, especially in a freehand *paper*-based sketch [3]. Shown in Figure 2a is a rough freehand sketch (a *scribble*) of a preliminary concept of a pool access floor for disabled persons generated by a practising product design engineer. This sketch contains geometry strokes showing the form of the floor as well as other strokes showing figures of persons etc. The complexity of automatically processing freehand sketches is augmented further due to the idiosyncratic way of sketching. Analysis of sketches generated by product design engineering students as part of their course work reveals that different sketching styles were used to express early form solutions for a common design task. The task concerned the design of a bin for a students' flat, capable of holding waste generated in one week. Figure 2b depicts sketches of the bin form concepts generated by two different students' design teams. Inconsistency in the sketching styles was evident despite the students' similar design education and sketching practice. Whilst colours were used in some sketches, other sketches were monochrome drawings (see Figure 2b). This suggests variations in the process by which the sketches were drawn. With regards to the output sketches, it can be observed that one sketch contains a series of form concepts expressed with 3D views whereas the other contains form concepts represented by 2D views (Figure 2b).

In view of the foregoing, it can be said that drawing standards for early form sketching are required for both levels listed in Section 1. The lack of such standards presents a bottleneck in providing designers with CAS support for early form sketching.



(a) *courtesy of* 4C Design Ltd.

(b) *courtesy of* Design Division, DMEM, University of Strathclyde

Figure 2. (a) co-existence of information types in (b) idiosyncrasy in sketching styles

3 STATE-OF-THE-ART APPROACHES TO EARLY FORM SKETCHING

A review was carried out encompassing manual and computer-assisted approaches to early form sketching. The review's scope was to identify their limitations with respect to providing a suitable paper-based drawing standard aimed at overcoming the difficulties highlighted in Section 2. Manual approaches included product design sketching strategies and existing standards on engineering drawing practices (Sub-section 3.1). Computer-assisted approaches included commercial CAGM systems and computer-aided sketching research prototype systems (Sub-section 3.2). Following is a summary of the review's key findings.

3.1 Manual approaches

Product design sketching techniques such as those found in [13] were reviewed. They are characterised by a sequence of steps, oriented towards aiding design practitioners to correctly depict, by for example keeping proportions and symmetry, a true shape of a form by means of a 3D projection. Perspective projection was the prevalent technique suggested. Such techniques are only *guidelines* on how to acquire 'form giving' skills through freehand sketching. Whilst they equip novice designers with such skills, they do not specify what requirements (e.g. pens, form representation) are most suitable to link early form sketching with CAGM.

Established drawing standards such as *BS8888:2004*, *JIS B 0001-2000*, *AS 1100.201-1992* and *DIN 406-10* were also examined with the scope of finding any reference to standards targeted specifically for linking early form sketching with CAGM. As expected, common to the reviewed standards was that their content focused explicitly on formal drawings generated in detail design. In BS ISO 10209-1:1992 (a cross-reference of BS8888:2004) only a definition of a 'sketch' is found. The absence of standards for early form sketching also applies for both the other BS8888:2004 documents and the aforementioned standards. For example, the AS 1100.201-1992 document contains a general overview of technical drawing principles (e.g. projection and section types). Yet a drawing standard enabling designers to automatically convert early form ideas expressed in sketches into 3D models is not considered.

3.2 Computer-assisted approaches

The review of commercial CAGM systems, such as *AliasStudio 13* [14], revealed that recent efforts have been made in bridging the gap between sketching and 3D modelling. Sketching-related functionalities incorporated in the reviewed CAGM systems, include importing scanned hand-made sketches, modelling over orthographic projection sketches, digital sketching and rendering environment and direct sketching on 3D CAD models. Common to these functionalities is the underlying principle of using freehand sketches as *templates* to guide the user in creating a 2D profile which is eventually mapped into a 3D model. In fact, despite the use of sketching, the user-interface of the reviewed systems still relies on the WIMP paradigm. Therefore, although they are promoting the notion of a sketch-based 3D modelling environment, commercial CAGM systems do not offer a drawing standard solution for paper-based early form sketching.

Two major modelling approaches were identified in research CAS prototype systems to map 3D geometric information from the sketch into a 3D virtual model. The first approach is based on the use of predefined modelling symbols [15] representing 3D operations (e.g. *extrude*) and 3D primitives (e.g. *sphere*) commonly found in CAGM systems. Whilst this approach contributes to overcome the difficulties of processing freehand sketched by computers, in its present form, it lacks the features of natural early form sketches. For example, Figures 3a and 3b illustrates the mapping of two simple forms from the corresponding input sketches. From the review it also emerged that a standard set of modelling symbols is still unavailable.

Reconstruction algorithms such as those described in [3] and [9] characterize the second modelling approach. Whilst this approach allows designers to express their early form ideas in a 3D projection (e.g. isometric), it is limited to polyhedral objects (see example in Figure 3c). It is untypical that early form sketches in the product design domain contain only polyhedral shapes. The system found in [16] reconstructs 3D models from sketches containing two 2D orthographic projections drawn according to standard drawing conventions. However, the system is constrained to just simple extruded shapes. In addition, the sketch has to be meticulously drawn, this making the system not suitable for early form sketching, where sketches are rapidly drawn.

Also the review clearly showed that research efforts are presently concentrated on using digital sketching devices such as a Tablet PC, thereby replacing the conventional pencil-and-paper sketching. At the same time, survey results in [17] clearly indicate that designers still prefer paper over digital media.

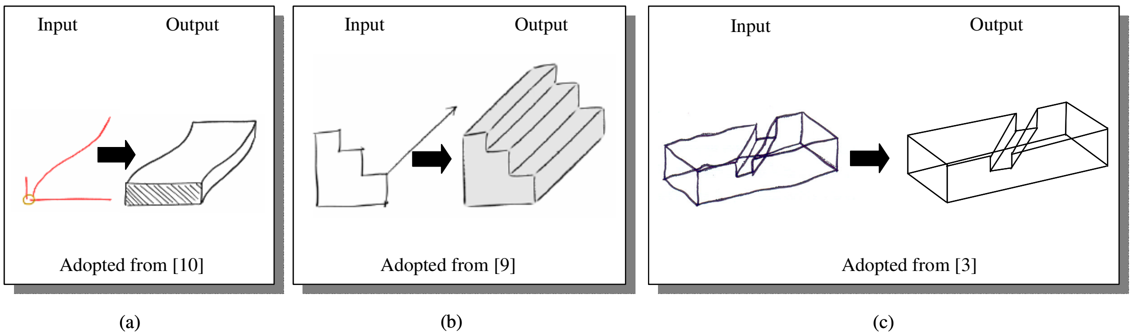


Figure 3. Examples of inputs in CAS prototypes and corresponding 3D model output

4 A DRAWING STANDARD FOR EARLY FORM DESIGN (DS_{EFD})

The envisaged benefits of CAS support combined with the review findings motivated the overall research goal. This research is concerned with the development of a *drawing standard* enabling designers to automatically obtain 3D CAD models directly from *paper*-based *early form sketches*.

In order to achieve the above goal and to evaluate the strengths and limitations of a preliminary standard, research efforts have been embarked on the representation of a single materialized entity in a sketch.

The underlying philosophy of the proposed *D*rawing *S*tandard for *E*arly *F*orm *D*esign (denoted by DS_{EFD}) is based on a trade-off between preserving sketching freedom and meeting the requirement of formality to automatically process hand-made sketches. Following are the specifications of DS_{EFD} according to the two levels referred to earlier.

4.1 DS_{EFD} specifications for the drawing process

The standard specifies a two-stage drawing process. In the first stage the concept is roughly sketched using *light strokes*. In the second stage, the designer draws standard elements (described in Sub-section 4.2) to formally define the geometry of the intended form idea. These elements are drawn superimposed on the first stage sketch. To allow a computer tool to distinguish between the sketch strokes and the standard elements, it is specified that the latter are drawn using *darker strokes*.

Therefore by adopting this drawing process, it is ensured that the designer's cognitive process is not obstructed with the use of predefined formal elements. This is because the rough nature of sketching is still maintained.
Furthermore, in order to maintain as much as possible the natural feel of traditional sketching, the standard specifies that the type of marker is *pencil*, whilst the medium is *paper*. With regards to the former, very faint (e.g. 6H) or very dark (e.g. 6B) graphite grades shall be avoided, as it is difficult for the computer to make clear distinctions in the grey levels. Ideally the HB grade shall be used. As regards to the drawing medium, the standard specifies that plain paper must be used. This is because lines present in, say, a graph paper, interfere with the process of extracting the form geometry information from the sketch.

4.2 *DS_{EFD}* specifications *for representing the form* geometry

Methods inspired by how 3D forms are traditionally depicted in drawings [18], such as the *spiral method*, are recommended to be used in stage 1. With the spiral method, the shape boundary is first sketched with constructive curves (see sketches in Figure 4). To create an impression of volume, spiral strokes are then drawn within the constructive curves. Note that multiple strokes are allowed (Figure 4). Multiple strokes which reflect the ill-defined nature of conceptual design are important to be maintained as they are a source for re-interpretation. As remarked in [19] the inherent nature of sketches leads to unexpected discovery of design ideas. Aside re-interpretation, another purpose of the light-stroke sketch is to guide the designer to draw and position the aforementioned elements specified by the drawing standard, as described next.

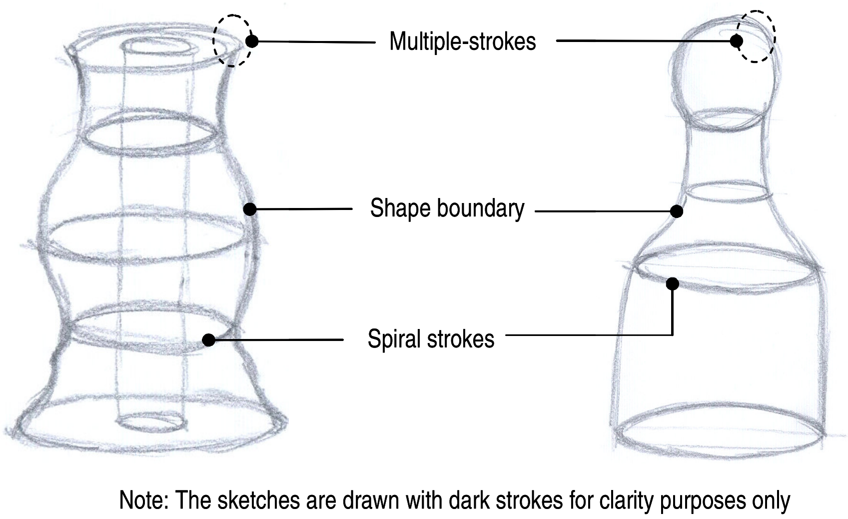
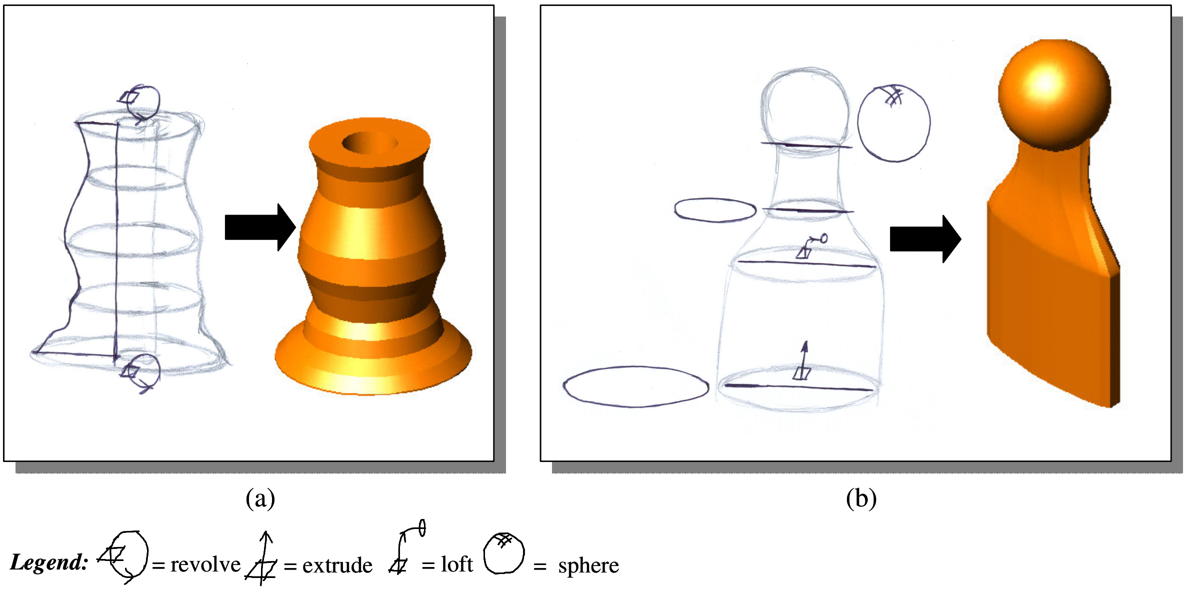


Figure 4. Examples of form concepts sketched using the spiral method

The use of *symbols*, *plane lines* and *cross-sectional profiles* is specified by the standard. By using the form case studies of Figure 4, following is an explanation of the purpose of these three elements.
As for any drawing standard, a set of predefined rules needs to be followed when using *DS_{EFD}*. One of these rules specifies how cross-section profiles should be drawn. For example, in case of rotational geometric forms, the cross-sectional profile should be drawn with thick strokes over the shape boundary drawn in stage 1, as shown in Figure 5a. To map the 2D cross-section into 3D, two *revolve* symbols are drawn, each one specifying a point on the axis of revolution (Figure 5a). For other geometries, where more than one cross-section is required, plane lines are required. The purpose of a plane line is to define the position and orientation of a plane in 3D space of a particular cross-section. A plane line represents the side of a plane projected perpendicularly to the surface of the paper (see pictorial illustration in Figure 6). The spiral strokes are used as reference to draw the plane lines (Figure 5b). Another rule specifies that a cross-section should be drawn near one of the endpoints of the respective plane line. When a cross-section is identical to its preceding one, it is not necessary for the designer to re-draw it. Placement of symbols near the midpoint of plane lines typifies another rule of the drawing standard (Figure 5b). In the case study of Figure 5b, two 3D operation symbols are required – extrude symbol which operates on the base cross-section and the loft symbol which operates on the last three cross-sections. With lofting, a 3D model is created by blending two or more

cross-sections. Besides 3D operation symbols, DS_{EFD} contains symbols representing 3D primitives (e.g. the sphere in Figure 5b). For clarity purposes, the sketches drawn in stage 1 are shown with dark pencil strokes, whereas the standard elements are shown in black ink. This applies for the rest of the relevant diagrams in this paper.



Note: For clarity purposes only, the sketches are shown with dark strokes and the elements representing the form in black ink

Figure 5. Forms represented with DS_{EFD} and the resulting 3D models

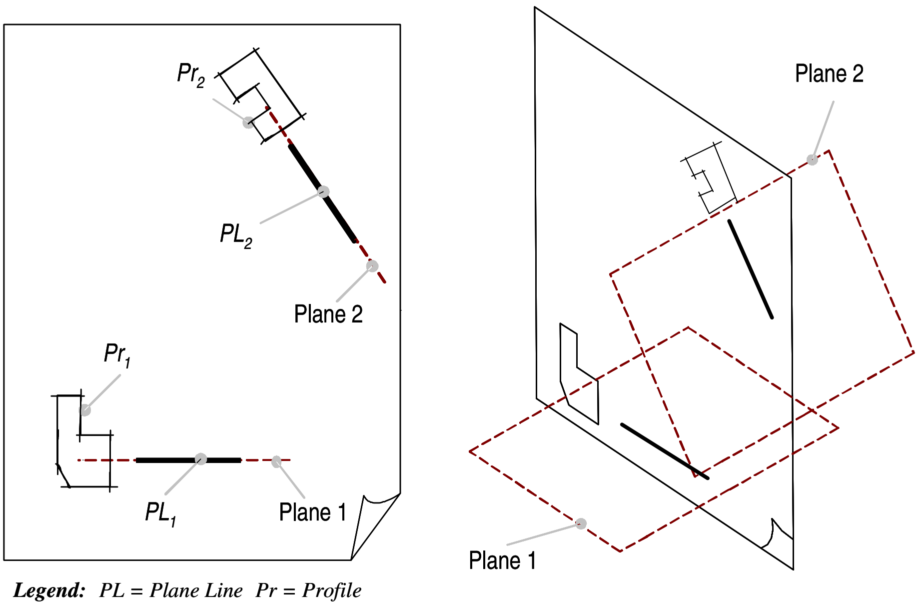


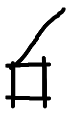
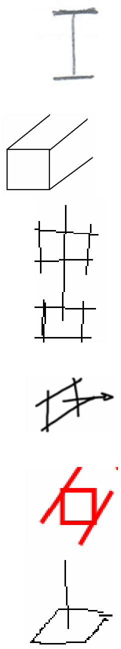
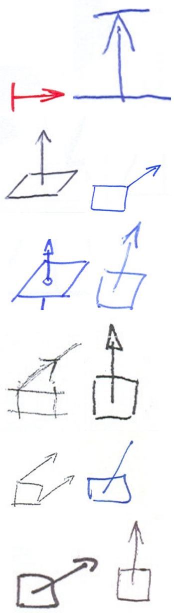
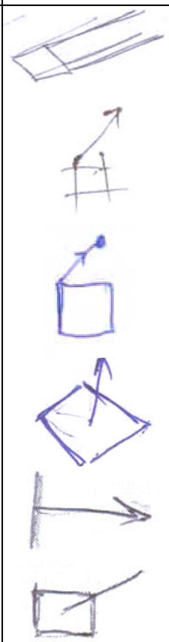
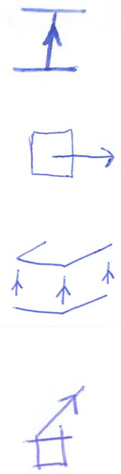
Figure 6. Representation of planes on which form cross-sections reside

Earlier in Sub-section 3.2 it was remarked that a standard set of 3D modelling symbols is unavailable. For this purpose, a survey directed to develop standard 3D operation and primitive symbols was conducted as overviewed next.

4.3 Development of standard 3D modelling symbols

The survey was carried out with a convenience sample comprising 103 students of varying design and cultural background. The questionnaire form was distributed in various countries including Denmark, France, Germany, India, Malta, UK and US. The aim of the survey was twofold. Firstly to assess the suitability of a *preliminary* set of symbols in representing the corresponding meaning and secondly to observe any commonalities in alternative symbols suggested by the participants. Only the key findings are included in this paper. Further details of the sample and results obtained are provided in [20]. The rating score given by the participants varied from one symbol to another. (The mean rating score ranged from 1.86 to 3.79, where a rate of 1 indicated a very strong positive attitude while a rate of 7 meant a very negative attitude). Commonalities between alternative graphical suggestions and written comments put forward by the participants were noticed within and across different groups in the sample. The inclusion of arrows, for example, was commonly proposed for the 3D operation symbols. Table 1 illustrates graphical examples of symbols alternative to the original extrude symbol. Although the examples are taken from different samples of participants, commonalties can still be noticed. The participants also requested for quickness in drawing the symbols as well as for more consistency between the preliminary symbols. Based on the survey results and on image processing requirements (such as having self-intersecting loops in each symbol), the symbols' structure was upgraded. Examples of the improved library of symbols are provided in Figure 7. Other improved symbols are used in the two examples of Figure 5.

Table 1. Symbols suggested by the participants as alternative to the extrude symbol

Original Symbol	Nationality of participants					
	British	Danish	French	German	Indian	Maltese
						

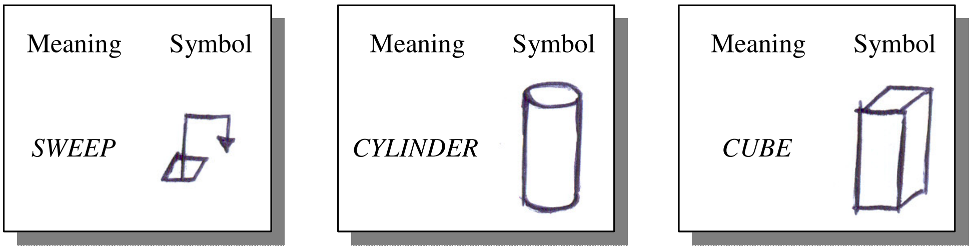


Figure 7. Examples of 3D modelling symbols specified by DS_{EFD}

5 *DS_{EFD}* EVALUATION

In view of the trade-off on which the drawing standard is based, the evaluation was directed to assess DS_{EFD} from the user's as well as from the computer's perspective.

5.1 Evaluation approach

5.1.1 Approach to assess DS_{EFD} from the user's perspective

The approach adopted to critically evaluate DS_{EFD} from the user's point of view consisted of a survey aimed to investigate whether the participants:

1. would find any objections in using light and dark strokes to distinguish between the form sketch and the elements by which the form geometry is formally represented;
2. would prefer to use two different colour pens instead of dark and light strokes drawn with the same pen;
3. had any suggestions to improve the proposed drawing standard;
4. would consider using DS_{EFD} if it allows the rapid creation of 3D models from paper sketches.

Prior to the delivery of the questionnaire form, the participants were given a flyer providing background to this research. By using two case studies similar to those of Figure 5, DS_{EFD} was explained. To measure the participants' attitude for evaluation objectives 2 and 4, '7-scale response' type questions were utilized; a rate of 1 implied a strong positive attitude, whilst a rate of 7 a strong negative attitude.

Two samples of participants were involved in the survey, purposely with different background and design experience. The first sample consisted of 5 Scottish practising product designers with an average of 11 years of experience in using CAD. The second sample comprised 21 Finish mechanical engineering design students with an average of 4 years of CAD experience.

5.1.2 Approach to assess DS_{EFD} from the computer's perspective

To computationally test DS_{EFD}, a prototype tool, *mX-Sketch* was developed. Implementation details go beyond the scope of this paper, however the reader may refer to [21] for further details. The modelling capability of the tool and hence of DS_{EFD} was tested by using a range of physical objects. Furthermore, different pencils were employed to assess the robustness of the tool in separating the light strokes of the form sketch from the darker elements specified by the standard.

5.2 Evaluation results

5.2.1 Survey results

The survey results revealed that 80% of the designers ($N = 4$) did not find any objections in using light and dark strokes as currently proposed. Only one designer opposed this approach. More evident was the opposition expressed by the students (57.1% found objections, 19% were in favour and the rest were not sure). The most common reason reported by the students was the subjectivity in correctly defining the grey levels coupled with the dependency on the type of pencil used. Two students remarked that by being vigilant in drawing with a certain grey level might be of hindrance during sketching. On the other hand, two designers stated that the use of different grey levels with a pencil is natural and intuitive.

A neutral opinion was expressed by the designers regarding the use of two different colour pens (an average rating of 4.4 was obtained). Students tended to opt for two colour pens (average rating of 3.05). However, a '*two independent samples t-test*' showed that there is no significant difference in these mean rating scores ($F = 0.128$, $df = 24$, $p = 0.169$). Contrasting comments were reported. Lessening computer misunderstanding between different pencil strokes was the prominent reason put forward by students favouring the use of colours. At the same time, one student commented that changing between colours would make sketching slower. Of the same opinion were two designers.

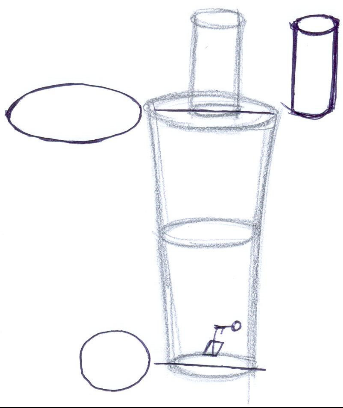
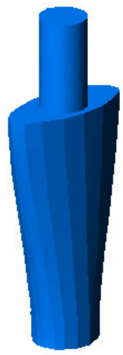
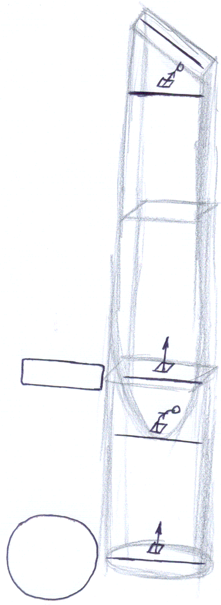
Relatively few suggestions were reported to improve DS_{EFD} per se. One reason attributed to this might have been that the participants had to provide recommendations based on their impressions rather than on hands-on experience of using the proposed standard. This factor was in fact noted by one designer. One designer questioned whether it is possible to use a dotted or dashed line to represent the axis of revolution, instead of two symbols. The ability to specify symmetrical profiles was a recommendation pinpointed by a student. Another student remarked whether it would be easier to input elements of DS_{EFD} directly by computer on the scanned sketch. Two other remarks related to the computer tool supporting DS_{EFD} concern the facility of adjusting the cross-sectional profiles once they have been constructed.

With regards to the acceptance of DS_{EFD}, it resulted that students were more positive compared to designers towards using it (mean ratings obtained were 2.67 and 4.6 respectively). Statistical analysis showed that the difference between the mean rating scores was significant (F = 0.001, df = 24, p = 0.021). This indicates that the scores were dependent upon the participants' background. One possible influencing factor concerns the level of sketching and CAD experience. For one designer the CAD models in Figure 5 do not show anything else than the respective sketches. On the other hand, one student noted that visualization of ideas would be easier. Faster communication of ideas with other people was also mentioned. Furthermore 24% of the students (N = 5) remarked that DS_{EFD} would contribute to quickly translate sketched form concepts into 3D models. In relation to this, whilst commenting that probably he would use DS_{EFD} for conceptual work, one designer stated that if fast enough, it would be very useful.

5.2.2 Testing of mX-Sketch

Various existing forms were utilized to test the modelling capability of *mX-Sketch* and subsequently of DS_{EFD}. Only two examples, namely, a perfumery bottle and of a vacuum cleaner nozzle are provided in this paper. From the respective sketch representation the 3D geometric model was constructed (see Table 2). General limitations encountered include the unsuitability of the standard in catering for hollow sections (common to the two objects under consideration) as well as for overlapping cross-sections and approximation of arcs by line segments.

Table 2. Examples of existing forms used to test DS_{EFD}

Physical object	Form representation with DS_{EFD}	Output 3D geometric model
		
		

As a preliminary test, three graphite pencils of different grades (4H, HB and 4B) but of the same make were employed to test the robustness of *mX-Sketch* to distinguish between the different strokes. Note that the sketches used in the test were generated by the same subject, so as to only keep one variable, i.e. different pencil grades.
As expected, light strokes which were classified as black pixels by *mX-Sketch* were more frequent when dark grade pencils (e.g. 4B) were used. This is due to the insignificant difference in grey levels between light and dark strokes. Yet it was observed that two factors strongly influence this occurrence - the density of light over-strokes and the difference in pressure applied by the subject during the process of drawing.

6 DISCUSSION AND FUTURE WORK

It may be argued that established drawing standards for detail design can be employed to standardize early form sketches. However, the manner of how early form design solutions are expressed in such sketches differ from the way 3D forms are presented with existing drawing standards. It is common practice that designers utilize cross-sections in their sketches to express complex shapes [13, 22]. An analysis, carried out by the author, of various sketches found in literature and accessible from sketchbooks of a practising product design engineer, evidence such a practice. In addition, the traditional methods of depicting 3D forms (such as the spiral method explained earlier) were also noticed. From the foregoing, the sketching approach adopted in stage 1 is justified. Despite this, it does not mean that principles used in established drawing standards cannot be employed in stage 2. For example, instead of two revolve symbols a simple line can be employed to indicate the axis of revolution of rotational geometries, as also recommended by one participating designer. Furthermore it may result that for certain form geometries it would be more feasible to use standard orthographic projections, rather than symbols as argued in [20]. In addition, the conventional perspective projection widely used in product design sketches [13] is not to be excluded. One possible way of incorporating such a projection is to allow the designer to sketch it prior to stage 1 of the current DS_{EFD}. This also applies for other elements of rough sketches which are presently not supported, such as shading and non-geometric information (e.g. annotation).
One of the crucial issues in DS_{EFD} is the approach to distinguish between the sketch and *PSL* elements. As a preliminary approach the use of different grey-level pencil strokes was investigated. The survey results indicate that although designers did not find any objections in using this approach, they were still undecided of whether using two colour pens as an alternative. Although the students seem to favour this alternative, however statistical analysis indicates that their positive mean rating was relatively insignificant compared to the designers' neutral rating. This implies that participants of both samples were not sure which approach is the most appropriate. The inconvenience of using two colour pens seems to be the participants' general concern of the second approach. On the other hand, the subjectivity in applying the correct pen pressure was mentioned by 28.6% (N = 6) of the students. The tests of *mX-Sketch* justify this main disadvantage of the current standard together with the strong dependence on other factors, even if using the same pencil. Therefore from the foregoing arguments, it can be said that evaluation based on comparative hands-on experiments is crucial to determine the better approach.
Survey results indicate that students were more willing than designers to use DS_{EFD}. However, the designers' mean rating score (4.6) was only marginally negative (a mean rating score of 4 indicates a neutral opinion). As previously noted the discrepancy between the samples' mean rating scores may have been attributed to the different participants' background. Furthermore the relatively simple case studies (of Figure 5) used in the questionnaire form to explain the DS_{EFD} might have had a influence on the designers' rating, given their more extensive CAD experience. Another influencing factor is the designers' similar working practice, given they were coming from the same company.
The tests with *mX-Sketch* reflect limitations as regards to the modelling capability of DS_{EFD}. Nonetheless other experiments revealed the potential of the standard and of the supporting computational framework, in particular for collaborative design [17, 21]. Since the computational framework on which *mX-Sketch* is founded, supports sketch image capture by means of cameraphones, it is possible for mobile designers to still remotely obtain 3D models on such portable devices directly from paper-based sketches. This facilitates the exchange of form ideas, as from conceptual design, between mobile designers situated at different remote locations.

Although this application is indicative of the benefits of a drawing standard for early form design in a collaborative design context, further work is required, in particular in the following directions:

- exploring ways of how principles from established drawing standards can be integrated within the present DS_{EFD};
- expansion of the range of forms that can be supported, including hollow sections;
- evaluation of the drawing standard (including the use of colours) based on hands-on experience.

In addition, another potential research avenue is to investigate the possibility of exploiting information embedded in the sketch drawn in stage 1 to complement the geometric information formally presented by the elements of DS_{EFD}.

7 CONCLUSIONS

This paper argued that designers require drawing standards if paper-based early form sketching is to be seamlessly integrated with CAGM. The literature review gives an overall picture on the current state in supporting early form sketching in this regard. The review findings collectively lead to the conclusion that a common deficiency in the state-of-the-art approaches concerns the lack of paper-based drawing standards directed to computer-assisted early form design. The research work disclosed in this paper contributed a step towards addressing this deficiency. Two are the novel aspects claimed in this paper which collectively distinguish this work from the state-of-the-art. The first aspect lies in the two-stage drawing process proposed in DS_{EFD}, which preserves the traditional pencil-and-paper sketching as well as supporting the automatic translation of early form concepts into 3D models. The second novel aspect of DS_{EFD} concerns the representation of a form concept in the drawn sketch. In particular, this paper contributed a new set of predefined 3D modelling symbols, designated on knowledge generated from a survey carried out with subjects of different design and cultural background on the one hand, and image processing issues on the other hand. The evaluation results collectively indicate that future work is required to improve the present DS_{EFD} before it can be used in practice. Nevertheless, to conclude it can be stated that DS_{EFD} contributes a step towards making 3D modelling technology available not only to designers but to other individuals in society who are skilful in sketching but who are computer illiterate.

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