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An Evaluation of a Language for Paper-based Form Sketching

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Abstract
Designers still sketch on paper to externalize their early form concepts. The user-interface of current Computer-Aided Geometric Modelling (CAGM) systems lacks the fluidity of sketching. Yet, such systems are still useful in conceptual design since they assist designers in visualizing an evolving form idea. The research disclosed in this paper is aimed at combining the benefits of paper-based freehand sketches with those of three-dimensional (3D) models. More specifically, this paper reports the on-going development of a *prescribed sketching language* (*PSL*) required to create a seamless link between *paper*-based form sketching and CAGM systems. Evaluation results revealed that whilst *PSL* is easy-to-learn, yet it requires improvements. Such a sketching language contributes a step towards simulating early form design solutions by the combined use of paper-based sketches and 3D models.

Keywords: computer-aided sketching, mobile design work, visual thinking, design simulation

1 Design problem background
Despite the importance of conceptual design, designers still lack computer support in rapidly modelling their form concepts in CAGM systems [1]. The main reason attributed to this concerns the stiff WIMP (Windows, Icons, Menus, and Pointing device) user-interface (UI) of such systems. In fact, owing to its efficacy in instantly capturing the flow of ideas, traditional pen-and-paper sketching is still very popular amongst designers to externalize their form concepts [1, 2]. The inadequacy of the UI of CAGM systems for conceptual design was pointed out by survey respondents as described in [3]. The UI-related weaknesses noted by these respondents include ‘too time consuming with slow feedback’, ‘too complicated for design thinking’, ‘a different feeling’ and ‘a difficult interface compared to pencil and paper.’ Another limitation of CAGM systems is that their use depends on the availability of a computer. As it is frequent that designers also think of ideas outside their office [4], conventional sketching media (e.g. a paper napkin) offer a great advantage over CAGM technology for *instant* externalisation of form ideas. Survey results in [4] reveal that more than 40% of the respondents, independent of their design experience, carry a piece of paper and pen on them on a regular basis to sketch ideas outside their usual workplace (see Figure

1a). Moreover, for such situations, traditional media were preferred over digital media (see Figure 1b). Thus these results indicate that despite the advent of digital devices, traditional sketching media are still preferred by designers to instantly express their ideas.

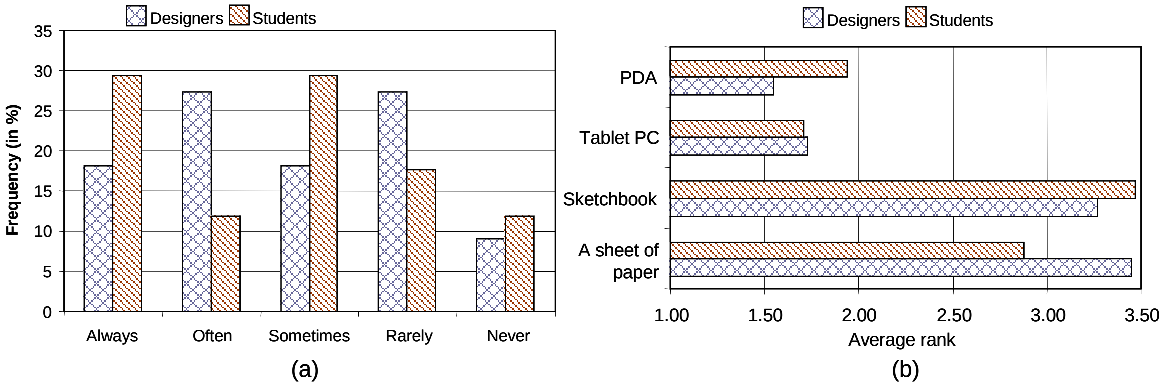


Figure 1. Frequency of carrying a paper, pen (b) preferred sketching media – adopted from [4]

In spite of the aforementioned limitations, CAGM systems are still useful for designers at an early design stage. 'Moving 3D models' are the most concrete and spatially specific means for visually supporting the development of design ideas [5]. Compared to a sketch, a 3D virtual model is more concrete in depicting the spatial appearance of a form idea. To integrate the benefits of these two visual representation support means (i.e. sketches and 3D virtual models) various *Computer-Aided Sketching* (CAS) tools have been developed. Yet, despite the importance of retaining the paper medium as argued above, research efforts in CAS technology were mostly focused on integrating *digital* sketching with CAGM systems [6]. In view of the above issues, designers currently lack *mobile* CAS tools which truly link *paper*-based sketching with 3D modelling technology.

2 Difficulties in automatic sketch recognition

Difficulties arise to process rough freehand sketches (i.e. scribbles) by computers. The complexity of automatic sketch recogntion is more pronounced in *off-line* CAS systems. In such systems, information is not captured in real-time from the evolving sketch (e.g. when processing scanned paper sketches). On the other hand in *on-line* CAS systems, dynamic information such as the spatial relation between consecutive sketch strokes can be exploited to facilitate recognition. Difficulties, especially in off-line CAS systems, also arise to separate geometric from non-geometric information which often co-exist in a sketch [7]. Figure 2a depicts a scribble of a faucet containing sketch strokes describing the faucet's geometry and other strokes showing water, tiles etc. The lack of 'drawing standards' for early form sketching combined with the ill-defined nature of a sketch make it further difficult for the computer to robustly recognize the designer's intent. For instance, does a sketched circular entity represent a hole, or an elliptical protruding feature? (see Figure 2b). Another difficulty is due to the idiosyncratic way of sketching [8]; designers draw the same entites differently (see Figure 2c). The above difficulties suggest that a means is required to help robustly build 3D virtual models truly representing the designer's form intent externalized in sketches.

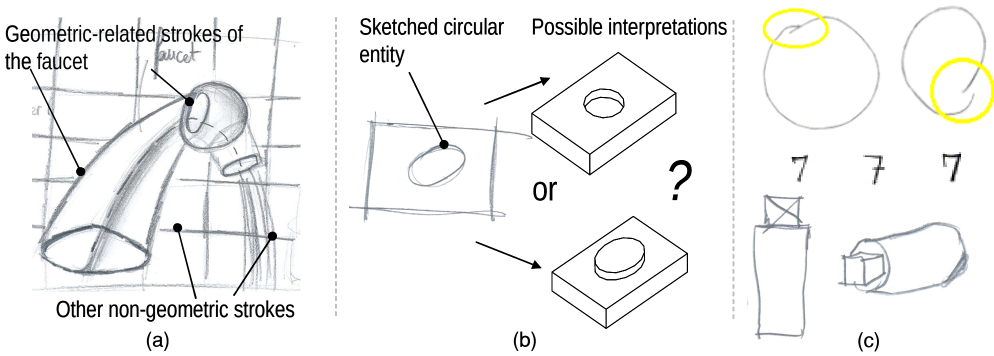


Figure 2. (a) Scribble of a faucet (b) possible sketch interpretations (c) entities sketched differently

3 Research goal and hypothesis

To address the design and the research problems outlined respectively in Sections 1 and 2, the overall research goal is to develop a *prescribed sketching language* (*PSL*). It is hypothesised that with *PSL* designers can suitably represent form concepts in paper-based sketches and at the same time allow the ***automatic*** and ***remote*** creation of the equivalent 3D models.

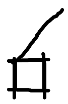
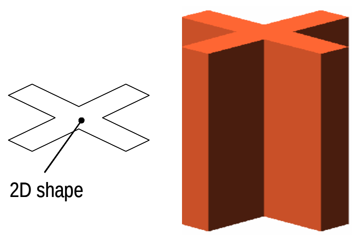
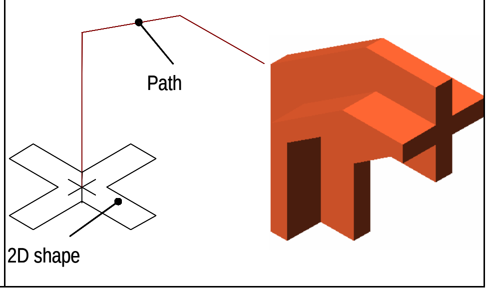
4 A prescribed sketching language (PSL)

Sketches and other forms of drawing are languages for handling design ideas [9]. In general, a language is based on a grammar which governs four elements, the alphabet, syntax, semantics and phonology [10]. The last element is irrelevant as PSL is a graphical language. In the context of this research, semantics refers to the geometric meaning of a form conveyed by PSL through the sketch. The next two sub-sections describe the alphabet and syntax of PSL.

4.1 Alphabet

The alphabet of *PSL*, $\{\alpha_{PSL}\}$ is constituted of three subsets of symbols, $\{3D_{OS}\}$, $\{3D_{PR}\}$ and $\{F_S\}$. The last subset consists of symbols of *form features* (such as pockets and threads). This paper will focus on the elements of $\{3D_{OS}\}$ and $\{3D_{PR}\}$. The first subset contains symbols representing *3D operations* (e.g. *extrude*), commonly found in CAGM systems. Table 1 shows how the mapping of 2D shapes into 3D models is accomplished through these symbols. The subset $\{3D_{PR}\}$ consists of symbols representing *3D primitives* such as cylinder, sphere, cone etc. An excerpt from the library of 3D primitive symbols is provided in Table 2.

Table 1. Symbols used in *PSL* to represent 3D modelling operations

Symbol/meaning	2D-to-3D mapping	Symbol/meaning	2D-to-3D mapping
 *<u>Extrude</u>: adds thickness to a 2D shape such that a 3D volume is obtained.*		 *<u>Sweep</u>: creates a 3D object by extruding a 2D shape along a <u>path</u>.*	

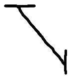
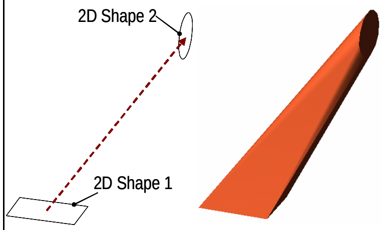
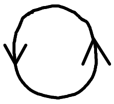
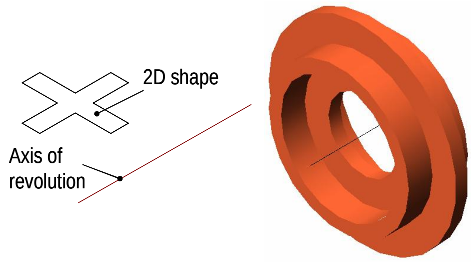
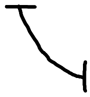
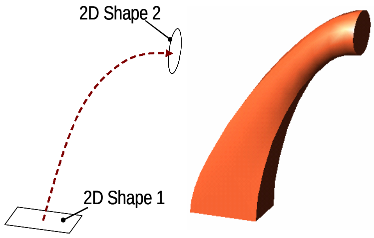
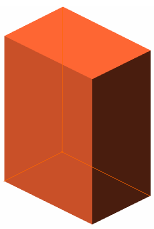
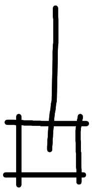
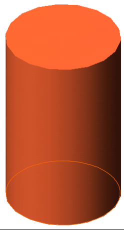
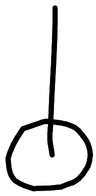
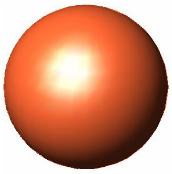
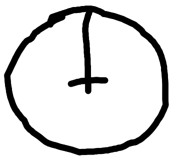
 *Straight Loft:* creates a 3D object by 'blending' it through a set of 2D shapes. A 3D object with *straight* edges results.		 *Revolve:* creates a 3D object by revolving a 2D shape about an axis.*	
 *Curved Loft:* similar to straight loft, except that blending is done with *curved* edges.		*In case of the revolve operation the symbol represents one point on the axis of revolution. This means that to define the axis, two symbols are required, one for each point.*	

Table 2. Excerpt from the library of 3D primitive symbols

3D primitive	Symbol	3D primitive	Symbol	3D primitive	Symbol
Cube 		*Cylinder* 		*Sphere* 	

4.2 Syntax

As illustrated in Figures 3a and 3b, *PSL* makes use of *plane lines* to define the planes of the form's *salient* cross-section profiles (see Figure 3a). By 'salient' it is meant those critical cross-sections, whereby if a 3D operation is applied on them, they will produce the intended 3D form. The 3D model shown in Figure 3c was created by operating curved lofting on the two salient profiles of Figure 3a. The language syntax establishes the rules which have to be observed to project a cross-section from its plane to the plane of the paper (see Figure 3b). With this projection method, a profile shall be drawn as if the respective plane is brought in the plane of the paper as indicated in Figure 3b. The syntax also specifies how the language elements (i.e. symbols, plane lines and profiles) shall be placed relative to each other. For example, the symbol is placed near the midpoint of the plane line PL_1 (see Figure 3a).

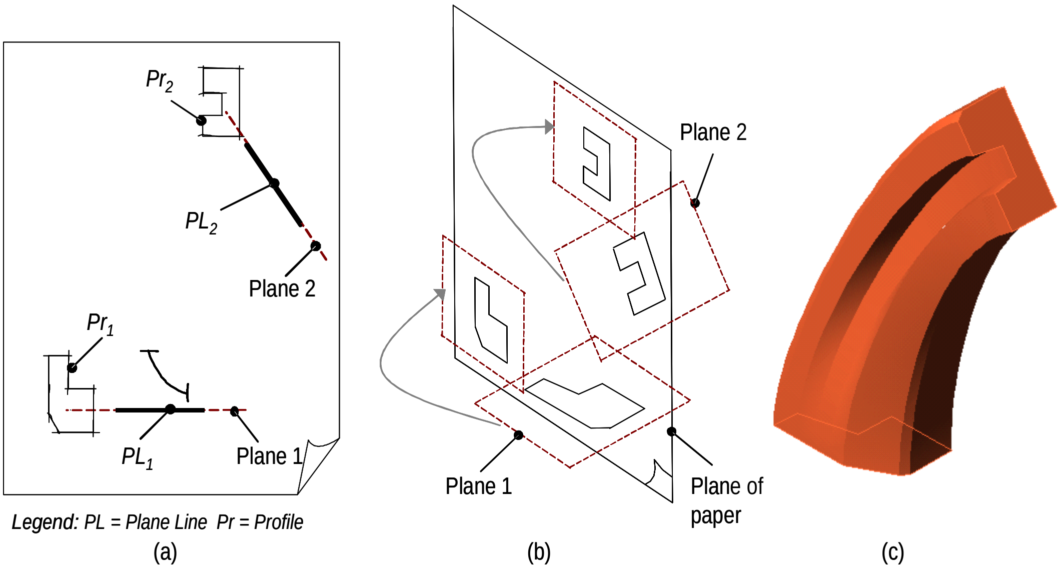


Figure 3. (a) Sketch drawn with PSL (b) projection of profiles (c) 3D model generated

5 Case studies of forms represented with *PSL*

Figure 4b depicts how the form concept of the faucet in the scribble of Figure 4a can be represented with *PSL*. Starting from the bottom, this form is defined by two salient cross-sections on which a curved lofting operation is applied. A sweep operation on Pr_2, along a path '*p*', then defines the last part. As indicated by its symbol, a sphere is constructed between these two parts, with its centre residing on the plane represented by PL_2. To preserve the designer's natural freehand sketching style, a two-stage sketching procedure is proposed. In the first stage scribbling is allowed, and in the second stage the form concept is represented with *PSL*. By processing the sketch drawn with *PSL*, the 3D virtual model of Figure 4c was created. Details of the computational framework architecture supporting *PSL* go beyond the scope of this paper. However the reader may refer to [4] for further details.

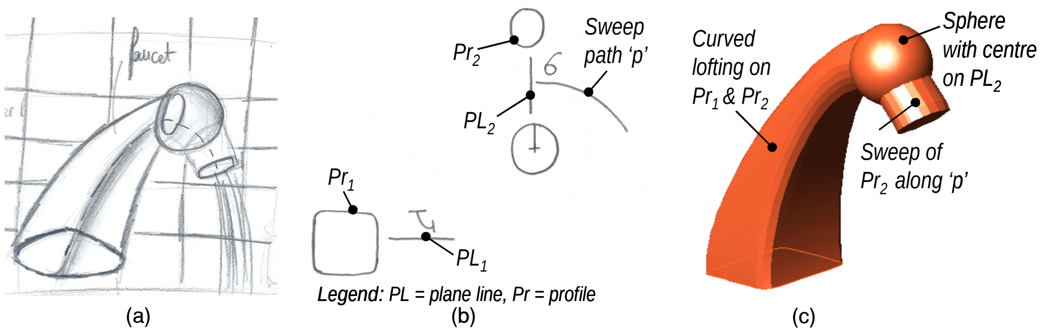


Figure 4. (a) Original scribble (b) representation of the faucet with *PSL* (c) 3D model generated

Figure 5 shows a perfumery bottle whose form is represented with *PSL*. It must be pointed out that currently it is not yet possible to utilize form feature symbols with the other symbols. Further, *PSL* does not cater for hollow forms. Owing to these limitations only the exterior *basic form* of the object was considered. For instance, the external thread on the neck of the bottle was omitted (see Figure 5a). Moreover, this object was assumed to be solid inside. Figures 5b to (d) show a decomposition of the sketch representing the bottle's basic form and the gradual construction of the resulting 3D model. The lower part of the bottle is defined by extruding the cross-section (Pr_1) with a length '*L*' (see Figure 5b). In stage 2, the upper part of the bottle is represented by a curved lofting operation applied on the cross-sections Pr_1 and Pr_2. Note that Pr_1 is also constructed on the plane represented by PL_2. Finally in stage 3, a cylinder, used to approximate the bottle's neck, is constructed with its base residing on the last plane (represented by PL_3). Note that presently the implemented tool supporting *PSL* approximates arcs to line segments. This is evident from the 3D models depicted in Figure 5.

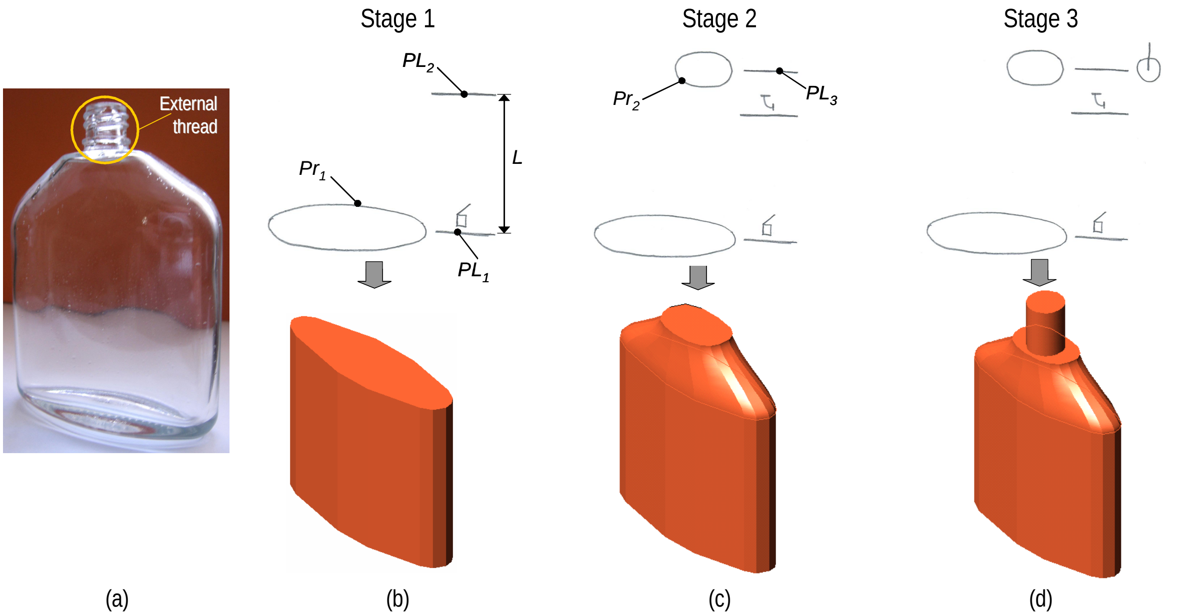


Figure 5. (a) Physical object (b)-(d) decomposition of its sketch representation & 3D model build-up

6 *PSL* Evaluation

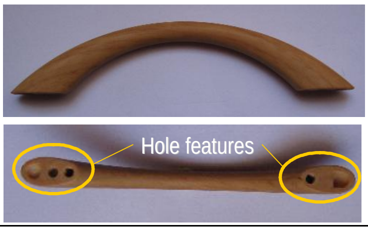
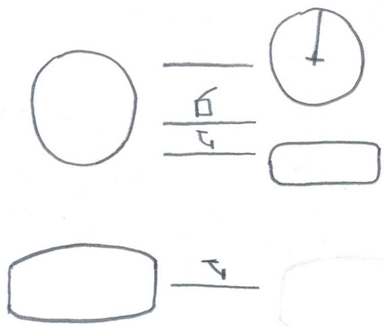
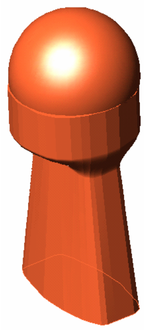
The primary scope of the evaluation was to assess the *ease-of-use* and the *utility* of *PSL* 'as-is'. The relevant specific objectives consisted of investigating whether or not the participants:

1. find it easy to understand the language underlying concepts;
2. find it easy to identify the profiles and the 3D operations required to represent a form;
3. agree that the symbols used in *PSL* are visually intuitive;
4. consider using *PSL* 'as-is' if it allows them to obtain 3D models from paper sketches.

6.1 Approach

Each participant was first given a 5-minute oral presentation on the research background. This was followed by a 25-minute verbal explanation on how *PSL* works. A language user's manual designated for beginners was utilised as a reference. In addition three physical objects were used to further explain *PSL*. The form of each of these three objects was sketched on paper with *PSL* by the evaluation investigator together with the participant. This exercise took an average of 13 minutes to complete. Next, three tasks were assigned to the participant, in which the perfumery bottle of Figure 5 and the two objects depicted in Table 3 had to be represented on paper using *PSL*. Note that due to the current language limitations, the hole features of the drawer handle were ignored (see Table 3). Moreover, the roll-on deodorant was assumed to consist of one part. The participant was given a quick reference sheet in which the symbols and their meaning were listed. The user's manual was also made available during execution of the tasks. After completion of the tasks, the participant was asked a set of questions on *PSL*, based on their impressions of using the language. This last evaluation step consisted of a *semi-structured interview* of approximately 30-minute duration. A digital recorder was utilized to collect qualitative data. To measure the participants' attitude '7-scale response' type questions were utilized; a rate of 1 implied a strong positive attitude, whilst a rate of 7 indicated a strong negative attitude. Interviewees were continuously urged by the interviewer to comment on their answer to provide as much qualitative data as possible.

Table 3. Objects used together with the perfumery bottle in the evaluation

	Physical Object	Paper-based sketch representation	3D virtual model generated
Drawer handle			
Roll-on deodorant bottle			

A pilot study with six undergraduate mechanical engineering students was conducted prior to the actual evaluation, in order to detect any weaknesses in the approach and in the interview questions. The pilot study showed that the above approach was adequate and that the questions were easy to comprehend. The only improvement made was a list of symbols provided to the participants for quick reference, as mentioned above.

6.2 Sample of participants

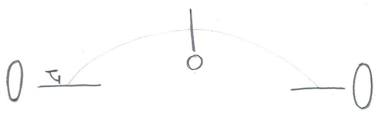
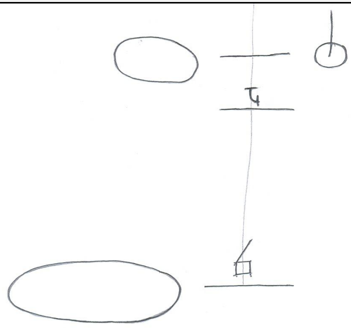
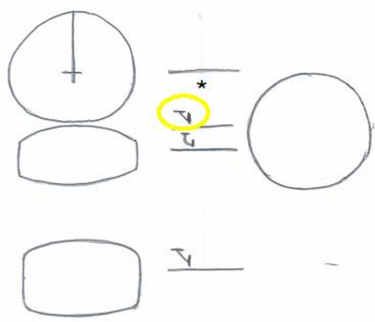
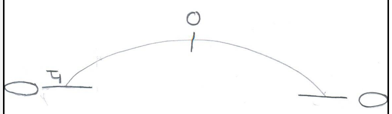
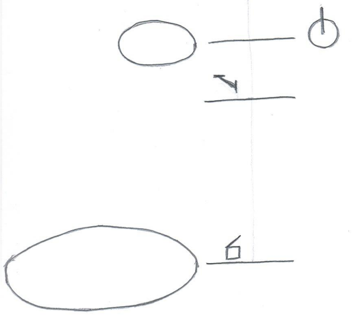
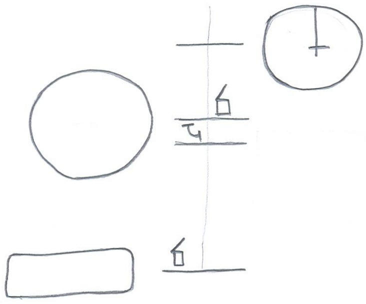
Seven male participants volunteered for this evaluation. They had a mean age of 42, an average of 16 years of design experience and an average of 8 years using CAGM systems. The participants included a Ph.D. student with experience in engineering design, a director of a design consultancy bureau, a practicing industrial designer, two practicing mechanical engineering designers, and two professors having past design experience and who teach subjects on sketching, engineering drawing and Computer-Aided Design (CAD) modelling.

6.3 Results

Numerical data was analysed using the ‘Statistical Package for Social Sciences’, *SPSS*® [11] with the scope to infer any conclusions from the given data. In this analysis, a statistical significance of 0.05 was used ($p < 0.05$). All the interviews were transcribed for qualitative data. The average time taken by the participants to represent the form of the drawer handle, perfumery bottle and roll-on deodorant bottle was respectively 1min 36s, 2mins 48s and 3mins 42s. From an analysis of the sketches generated, it resulted that 5 participants drew the two oval cross-sections at the ends of the drawer handle in a horizontal position instead of vertical (compare relevant sketches in Table 4). The main reason attributed to this was the new projection method proposed in *PSL* to draw a cross-section. Regarding the perfumery bottle, 5 participants guessed correctly its sketch representation. The other two participants selected a straight lofting instead of a curved lofting operation for the object’s upper part. Yet, the representation of this part of the perfumery bottle was subjective, depending on the number of cross-sections taken. Similarly, for the bottom part of the roll-on deodorant bottle, 4 participants opted for a curved lofting operation instead for a straight lofting operation.

However, in this case, the difference in the resulting 3D models would not have been significant. Of more importance is that two participants approximated the bottom part of the roll-on deodorant bottle with an extrude operation (see incorrect sketch in Table 4). This may have resulted due to the transparency of this part of the bottle. As commented by one of the interviewees, a transparent part may lead to difficulty in detecting its salient cross-sections.

Table 4. Examples of (in)correct sketches produced by the participants

	Drawer Handle	Perfumery Bottle	Roll-on deodorant Bottle
Correct Sketch			
Incorrect sketch			

**Straight lofting operating on two identical sections yields the same result as extruding one of the sections.*

The results obtained for evaluation objective (1) revealed that the mean rating score given by participants in understanding how *PSL* works was 2, thus indicating a positive attitude (a rate of 1 implied a strong positive attitude). Statistical analysis shows that there is a medium correlation between the participants' rating in understanding *PSL* and their CAD experience (*r*-value = -0.506). The negative value implies that with increasing CAD experience, participants found it less difficult to understand *PSL*. In fact, two interviewees remarked that their experience in using CAD systems facilitated their language understanding. Yet this correlation is insignificant, as reflected in the p-value obtained (p = 0.246) which is higher than the level of significance (p = 0.05). Two participants commented that they would have difficulties in using new projection methods such as that proposed in *PSL*.

The mean rating scores obtained for assessing the participants' easiness in identifying the salient cross-sections of the drawer handle, perfumery bottle and roll-on deodorant bottle were respectively 2.43, 1.29 and 1.57 (a score of 1 implied a strong positive attitude). Therefore, in all tasks, the participants found it easy to identify the objects' cross-sections. These scores also suggest that the drawer handle presented the major difficulty. However, this result does not reflect the actual difficulty experienced by the participants in *identifying* the handle's critical cross-sections, but rather in determining their correct orientation, as previously mentioned. On the other hand, results show that the participants found it most easy to identify the 3D operation required for the drawer handle (a mean rating score of 1.43 was obtained). Higher scores were obtained for the perfumery and roll-on deodorant bottles (2.29

and 3.14 respectively). The difficulty in selecting the correct type of lofting operation was the main cause attributed to these scores.

The participants showed a positive attitude towards the symbols used in the language. A mean rating score of 2 was obtained, suggesting that they agreed that the symbols employed are visually intuitive. One participant pointed out that the loft symbols might be confusing as the straight and curved lines in the symbols seem to be more indicative of the *route* of lofting rather than the edges of the resulting lofted body. Another participant commented that the symbols must be fast-to-draw. For instance, this participant suggested removing one of the arrows of the symbol; the resulting symbol could be exploited to indicate half a revolution.

The results obtained for evaluation objective (4) showed that the participants expressed a neutral opinion (i.e. a mean rating of 4) on using *PSL* ‘as-is’, even if this would allow them to rapidly obtain 3D models from paper-based sketches. From the feedback received from the participants the following two main observations were made. Participants with an engineering design background deem as important for such a sketching language to cater for more than one form, rather than for single components as is the case with the current language. The main reason is that a lot of concepts they generate in sketches are more function than form oriented. Subsequently their sketches usually contain more than one component. Another observation was that only one participant showed reluctance towards using a symbol-based sketching language. This participant (an industrial designer) added that he does not like to use symbols; when using his PDA, he makes use of the touch pad to enter characters rather than using the PDA’s graffiti gesture set. The rest of the participants did not express any objection towards the notion of ‘sketching by symbols.’

7 Discussion and future work

It can be argued that for the participants, *PSL* was a new sketching language whose underlying concepts were explained to them in a short period of time. Yet, the sketches produced quickly by the participants and the positive evaluation results achieved for objectives (1) to (2), collectively show that they grasped the language well and hence found it *easy-to-learn*. As remarked by one of the interviewees, the language understanding is greatly enhanced by practicing and by experimentation. The results also suggest that *PSL* needs to be refined to make it easier to use, as evident from the difficulty exhibited by the participants in using the new proposed projection method. Yet, this has to be put in the perspective of the short practicing time the participants had in using *PSL*. A worthnoting issue related to the results achieved on the ease-of-use of *PSL* is that the participants were provided with the *physical* objects. In reality, *PSL* is intended to be used at that instant when a provisional form design solution has been externalized in a scribble. As illustrated in Figure 6, the scribble is the output of design synthesis in the *basic design cycle* [12]. It would be interesting to test the language’s ease-of-use when participants have to identify the form’s salient cross-sections, 3D operations etc., from *scribbles* instead of from physical objects.

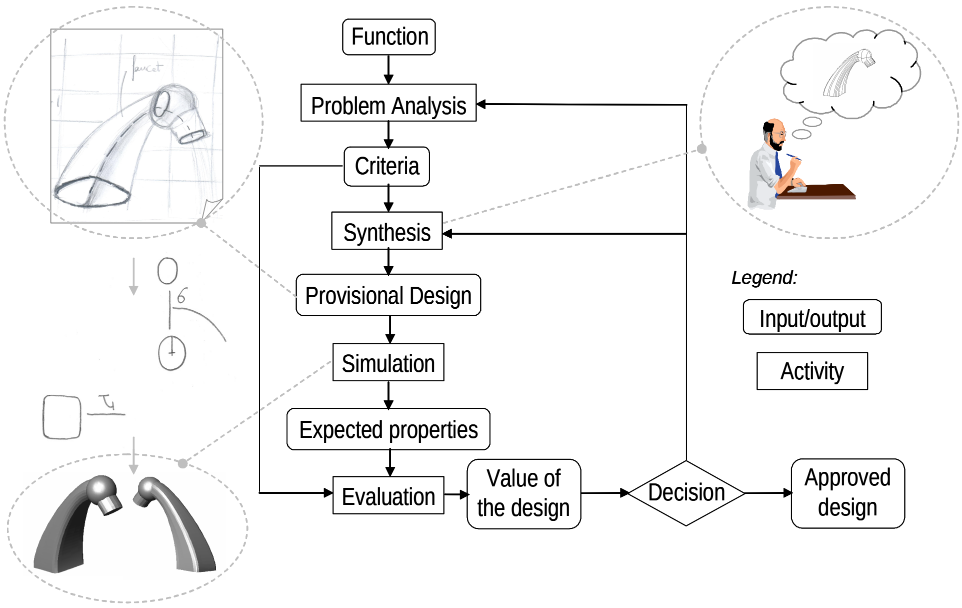


Figure 6. Intended use of *PSL* in the basic design cycle

It seems that the participants accepted the notion of a sketching language based on symbols. As previously mentioned, it was only one participant who was reluctant to use such a language. It can also be argued that the neutral mean rating score of 4 obtained for the usefulness of *PSL* ‘as-is’ together with the reasons put forward by the participants collectively indicate that a prescribed sketching language would be useful. Yet the qualitative results show that the *current* language needs to be further developed before it can be used in practice. For engineering designers, in particular, the language shall support more than one form, and subsequently it shall cater for function. The utility of *PSL* can also be tested by examining how useful it would be in assisting designers to rapidly simulate a provisional form design solution through a 3D CAD model generated from a sketch (see Figure 6). A simple sketch may not be sufficient for a designer to adequately visualise the spatial properties of a form design solution; in such a case a 3D model would be required.

Based on the participants’ feedback, the following future tasks are proposed to enhance the ease-of-use and the utility of *PSL*:

1. altering the current projection method, such that it will be more user-friendly;
2. extending the range of forms that can be supported, e.g. hollow objects;
3. developing *PSL* further such that it can support the form representation of more than one component and subsequently their relative spatial arrangement in an assembly;
4. enriching the language alphabet to cater for function representation, by including, say, arrows to indicate movement between two components;
5. carrying out comparative experiments to examine the effectiveness of the combined use of sketches and 3D models when compared to using sketches alone, in simulating form solution concepts.

8 Conclusions

To conclude it can be stated that this paper contributes a novel sketching language linking paper-based sketches with 3D models, two widely used visual representation aids in design. The disclosed results demonstrate that although the current language is easy-to-learn, yet, as discussed, the results also indicate that it needs to be refined to enhance both its user-friendliness and its utility. As conjectured, compared to sketches alone, the combined use of sketches and 3D models may result in a more effective approach for designers in simulating their form concepts. A prescribed sketching language would contribute towards this approach.

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