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Investigating user preferences in utilizing a 2D paper or 3D sketch based interface for creating 3D virtual models

A report detailing the work carried in collaboration with Fraunhofer IPK, supported by Visionair

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Abstract

Computer modelling of 2D drawings is becoming increasingly popular in modern design as can be witnessed in the shift of modern computer modelling applications from software requiring specialised training to ones targeted for the general consumer market. Despite this, traditional sketching is still prevalent in design, particularly so in the early design stages. Thus, research trends in computer-aided modelling focus on the the development of sketch based interfaces that are as natural as possible. In this report, we present a hybrid sketch based interface which allows the user to make draw sketches using offline as well as online sketching modalities, displaying the 3D models in an immersive setup, thus linking the object interaction possible through immersive modelling to the flexibility allowed by paper-based sketching. The interface was evaluated in a user study which shows that such a hybrid system can be considered as having pragmatic and hedonic value.

1 INTRODUCTION

Computer modelling of 2D drawings is becoming increasingly popular in modern design [1] and this can be observed in the shift in computer modelling applications from software such as AutoCAD [2] and CATIA [3] among others, targeted for engineers and architects to others such as Sketch-Up [4] among others, which target the general consumer market. Despite the fact that commercial computer modelling interfaces are becoming more user-friendly, they are primarily based on window, icon, menu and pointer (WIMP) interfaces which contrast with the ease and flexibility with which pen and paper sketches can be created [5, 6].
Thus, paper-based sketches are still popularly used by designers to sketch initial ideas. Although not necessarily accurate, sketches, allow the designer to start depicting his ideas and build on them, creating flat, 2D representations of the designer's initial ideas.
Thus, pen and paper sketching has an important role in the design process, allowing the artist to externalise thought concepts quickly and efficiently [1, 7]. In addition, since human observers can understand 2D drawings as abstractions of the 3D world, artists can use sketches as effective communications tools [5]. This is particularly useful in commercial design, allowing the artist to present the client with initial designs before the final construction begins [1]. In modern design

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however, the computer modelling software provides for enhanced graphics, such as virtual walk-through and dynamic interaction, which augment the level of communication between the artist and client [7], such that computer models of the initial designs also have an important role in the design process. Therefore, the initial design stage will typically involve quick pen and paper sketches which are then re-drawn, sometimes by dedicated artists, with computer modelling software [8, 9].

The research trend in computer-based modelling focuses on bridging the gap between pen and paper sketching and the WIMP interfaces by creating sketch-based interfaces (SBIs) that are as natural as possible [10]. Thus, bringing together the sketching flexibility of pen-and-paper sketching with computer-based modelling.

In this report, we build on the paper-based SBI and immersive modelling environments described in [11] and [12] respectively to create a new SBI that combines 2D sketching with immersive 3D modelling. This interface differs from others described in the literature in that 2D sketching can be performed online within the immersive environment and in an offline environment, such that 3D models can be projected in the immersive environment from the user pen-and-paper sketches, thus creating a hybrid SBI that accepts online and offline sketching as input. We also report the results of a user study performed using both sketching modalities, hence observing the user's perception to the new interface.

The rest of this report is organised as follows: Section 2 presents the related work; Section 3 presents our proposed sketch-based interface; the methodology employed for the user evaluation is presented in Section 4, with results discussed in Section 5, while Section 6 concludes the report.

2 RELATED WORK

Sketch based interfaces generally incorporate gestures and sketching to allow the user to create 3D models from drawings. Gestures, which can be created using tools and instruments like pens, can range from simple editing commands such as the deletion of strokes, to more complex, 3D modelling commands such as extrusion and lofting commands [13, 14]. To help the user visualise the effect of the gesture, it is common practice for SBIs to temporarily visualise the gesture trace as lines or strokes. Gestures therefore facilitate the interpretation of the sketch, but require that the user has a good knowledge of the gestures and their actions. Thus, sketched based interfaces reach a balance between sketching freedom and the use of gestures which aid the interpretation of the sketch.

One such interface is CHATEAUX [15] which allows the artist to sketch in 3D, providing thumbnails with different possibilities with which a sequence of strokes can be completed. While such a suggestive interface can help speed up the modelling process, it is somewhat intrusive, limiting the design exploration to the suggested models provided by the interface. Less intrusive interfaces which also provide more drawing flexibility are attained through blob-like inflations of 2D contours, such as TEDDY [16] and SHAPESHOP [17] among others. These allow the designer to create blob-like models from the contours. By allowing creating models from sketched contours, these interfaces provide for a natural drawing style, however, the inflations used for the 3D modelling limit the applicability of these interfaces to blob-like models. To amend this, additional sketched gestures in the 3D space are required to mold the model into the desired shape. Such gestures could range from simple inflation or deflation of the blob-like model to more complex deformation tools that are loosely modelled on deformations that are used to form clay sculptures, with DIGITAL CLAY [7] and FIBREMESH [18] providing examples of such interfaces.

These sketching modalities can be extended to introduce fully immersive drawing [12, 19], whereby a rendering system and an optical tracking system to allow the user to sketch and interact with 3D objects in a virtual environment within a five-sided CAVE. Freehand drawing and modelling are carried out using three tangible interfaces, namely a stylus to draw virtual ink in the virtual environment, a pair of pliers which allow the user to group, reposition and release virtual objects in the CAVE and a Bezier-tool which allows the user to extrude a Bezier curve in 3D space, following the movement of a two-handed tool [20]. With this system, users are not restricted to any particular gestures or sketching language and therefore, after overcoming the missing physical sketching medium, users are allowed greater sketching freedom than other interfaces mentioned earlier. Moreover, it has been shown that designers are able to learn the necessary interaction techniques to interact with the immersive environment, albeit with a rather steep learning curve [21].

These interfaces model the 3D geometries incrementally, building the 3D shape as the user sketches and makes use of gestures. Sketching must therefore be carried out in an online fashion and, in the particular case of Israel et al. [12], within the immersive environment, thus precluding the use of pen-and-paper sketching. In contrast, Bartolo et al. [11] describe a sketching interface which infers the 3D geometry of the sketch in an offline manner, allowing the user to sketch with real ink on real paper, as well as with digital ink on graphic tablets. Although this SBI allows the user to obtain 3D models from offline sketches, the SBI does not offer support for further interaction with the 3D model, such that, if any part of the object needs modification, the user must either redraw the sketch or port the 3D model to some other SBI. In the latter case, the user must engage with the object using the different sketching rules of the second interface. Ideally, a user will have an SBI that allows for offline and online sketching modalities, providing for consistency between the two modalities.

3 A HYBRID SKETCH BASED INTERFACE

In this work, we build upon the offline SBI described in [11] and the immersive modelling described in [12] to create a preliminary hybrid SBI that allows for offline and online sketching modalities by means of a common sketching language. Thus, users who do not have immediate access to an immersive environment can sketch a representation of the desired 3D model using pen-and-paper or a graphics tablet in an offline manner, using the same sketching language one would use within the immersive environment. The 3D model obtained after processing the sketch can then be represented in the immersive environment at no additional effort to the user. On the other hand, users familiar with 2D drawings, in particular engineering drawing standards, and perhaps not overly comfortable with drawing directly within the 3D environment, may still use the immersive environment to create 3D models quickly, using a sketching language that is familiar from engineering drawing experience. Hence, the proposed hybrid sketch based interface will offer the user the possibility to obtain a 3D model irrespective of the sketching modality, giving users of both modalities the possibility to create virtual models which can then be manipulated using established techniques described in the literature.

3.1 Objects that can be modelled

Using this preliminary SBI, the user will be able to create 3D models of objects that have a single axis, however, the object does not need to be symmetric about this axis. The interface assumes that the topmost and bottommost cross-sections are flat, while the bottommost cross-section must be drawn such that it is in a horizontal position.

3.2 The sketching language

Designers using this sketching interface are required to follow two drawing steps, namely the scribbling step and the annotation step. In the first step, designer sketches the *longitudinal sketch*, thus communicating with the interpretation algorithm the intended shape of the object. In the annotation step, the designer annotates this longitudinal sketch using *cross-sectional profiles* as shown in Figure 1(a).

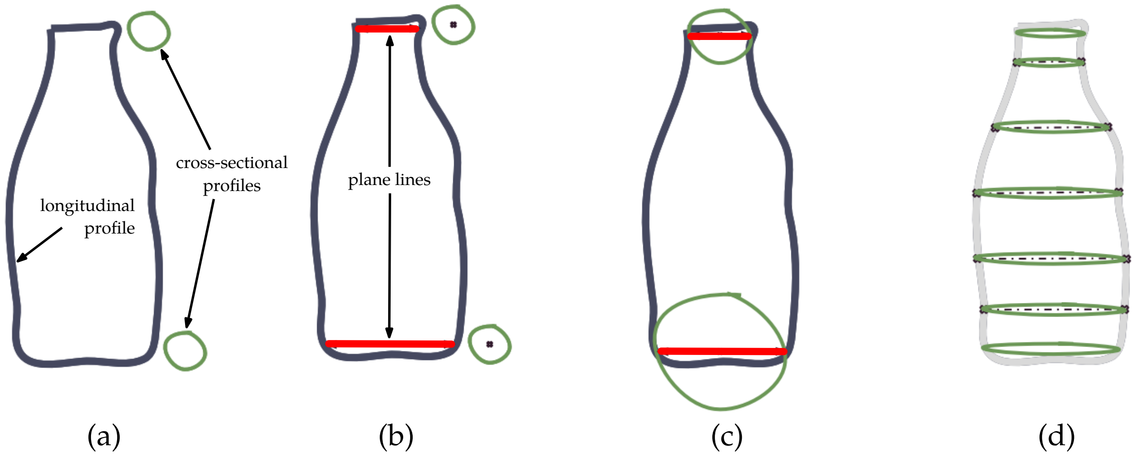


Figure 1: (a) Example of a sketch drawn by the user, consisting of a longitudinal profile and cross-sectional profiles [22]. (b) Plane lines are projected onto the longitudinal profile from the centre of gravity of the cross-sectional profile and orthogonal to the longitudinal sketch. (c) The cross-sectional profiles are centred and scaled to the size specified by the plane lines. (d) The longitudinal profile is sampled to create intermediary profiles for which the cross-sectional shape is determined from the user-defined cross-sectional profiles, hence defining the shape of the 3D model.

The cross-sectional profiles are used to resolve the ambiguities that arise when 3D objects are represented on a flat plane while allowing the designers to model non-polyhedral objects that may have any arbitrary shape. The use of cross-sectional profiles is inspired from the concept of removed sections as described in the BS8888:2002 drawing standards [11] such that the cross-sectional profiles may be compared to successive removed sections which indicate the object's cross-sectional shape at consecutive cutting planes. Thus, the sketching interface minimizes the initial learning curve required to use the interface by using annotation rules that are natural to the designer.

The cross-sectional profiles must be positioned such that the centre of the cross-sectional profile corresponds to the position on the longitudinal sketch on which they must reside. It is also necessary to ensure that the cross-sectional profiles do not intersect any other annotation or the object profile. Furthermore, the cross-sectional profiles are used to give information about the shape and not the actual size of the object's cross-section, thus allowing the user to draw the cross-sectional profiles in a convenient size, freeing the user from the burden of scaling each new cross-sectional profile with respect to the previous cross-sectional profiles. This is possible since the actual size of the object will be determined by the interpretation algorithms from the shape information present in the longitudinal sketch.

3.3 Preparation to extract the 3D structure

Prior to obtaining the 3D shape information from the drawing, it is necessary to re-group the information into components which are representative of the different parts of the 3D object. Each component should consist of two cross-sectional profiles which define the cross-sectional shape of the object at the initial and final cross-sectional planes of the component and two segments of the longitudinal sketch that define the shape of the 3D object between these planes. A hierarchical representation of these components will enable the interpretation algorithm to determine the 3D shape of the intended object. The segmentation of the longitudinal sketch into its components is carried out at reference points determined from the cross-sectional profiles.

Since the cross-sectional profile is allowed to have any arbitrary shape, this reference point is selected as the centre of the bounding box that fits around the cross-sectional profile, thus using a point that is close to the centre of the profile. A straight line, orthogonal to the longitudinal profile is projected from this reference point onto the longitudinal sketch, as shown in Figure 1(b). Such a line is referred to as a *plane line* in engineering design drawing terminology and is used to segment the longitudinal sketch into its components, using the intersection point between this line and the longitudinal sketch as the point for segmentation. Each cross-sectional profile is then automatically associated with the final plane of the current component and the initial plane of the subsequent component.

In this simple manner, the user can fully specify the 3D geometry of the object in the 2D planar space. The interpretation algorithms are then required to determine the scale and position of the cross-sectional profiles in order to create the 3D object. The next step of the interpretation algorithm is to extract the 3D geometry from the hierarchical structure of components. Thus, it is necessary to determine the position in the 3D space of the defined cross-sectional profiles from which the position and shape of the object cross-sections at intermediary planes may be obtained.

The cross-sectional profiles drawn by the designer give the basic skeleton of the 3D model. Since the user is not required to sketch these to scale, the cross-sectional profiles must be first scaled to their actual size. The scaling factor required may be defined as $\frac{w_l}{w_p}$ where w_l is the width of the longitudinal sketch, obtained from the projected plane line and w_p is the width of the bounding box enclosing the cross-sectional profile. The cross-sectional profiles are then translated onto the longitudinal sketch such that the centre of the bounding box enclosing the cross-sectional profile coincides with the midpoint of the associated projected plane line as shown in Figure 1(c).

Once the cross-sectional profile has been properly scaled and its proper position determined, it must be rotated to obtain a representation of the profile on a width vs breadth axis as shown. This is necessary as it allows us to map the 2D profile into 3D space. In generating the 3D shape information, it is assumed that the origin of the origin of the 3D coordinate system lies on the centre of the bottom-most plane line and therefore, on the outer contour of the bottom plane of the object. Using this co-ordinate system, the breadth of the cross-sectional profile is mapped directly to the y-axis, while the width of the cross-sectional profile is mapped onto the x-axis and z-axis using $x = w(\sin\theta + \cos\theta)$ and $z = w(\cos\theta - \sin\theta)$ where θ is the angle the plane line makes with the 2D horizontal axis. Since the object is not necessarily required to be vertical above the base cross-sectional plane, cross-sectional profiles above this base plane require addition of the horizontal and vertical displacement of the centre of their plane line from the base plane line to the x-axis and z-axis respectively.

Note that users are only required to specify the planes where significant changes in the cross-sectional profile of the object occur which results in a coarse representation of the 3D object shape. The longitudinal sketch will however give information on the more subtle shape information such that it is necessary to define intermediate plane lines which allows the interpretation algorithm to create a 3D model that more accurately defines the designer's intent. Thus it is necessary to determine the shape of intermediate cross-sectional profiles and this is obtained by morphing the cross-sectional profile at a particular plane into the shape specified in the successive plane. This is achieved by sampling the cross-sectional profiles associated with a component such that they each have n order sample points where the starting point of each profile is taken to be the top right point in the profile. In this manner points from the first cross-sectional profile can be matched to the second profile. Straight line segments can then be drawn from matching points and these segments can be divided into m equal subdivisions such that shape of intermediary cross-sectional profiles may be defined by the coordinates of the points on the same subdivision m_i as shown in Figure 2.

These intermediary cross-sectional shapes must be placed in the context of the scribbled profile and must therefore be positioned and scaled according to the shape information present in

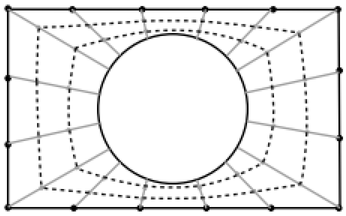


Figure 2: Example of morphing a rectangular cross-sectional profile into a circular one to obtain the shape of the intermediary cross-sectional profiles [11].

the scribble. To achieve this m intermediary plane lines, corresponding to the number of intermediary cross-sectional profiles generated by the morphing algorithm, must be created. Thus, the two edges of the longitudinal profile are sampled and points of correspondence between the two scribbled edges are determined. These points form the endpoints of the intermediary plane lines as shown in Figure 1(d). The size and orientation of these plane lines are used to determine the scale and orientation of the intermediary cross-sectional profiles. In this way, it would be possible to create 3D representations of concave and convex objects as well as of objects which are not symmetric about the vertical axis.

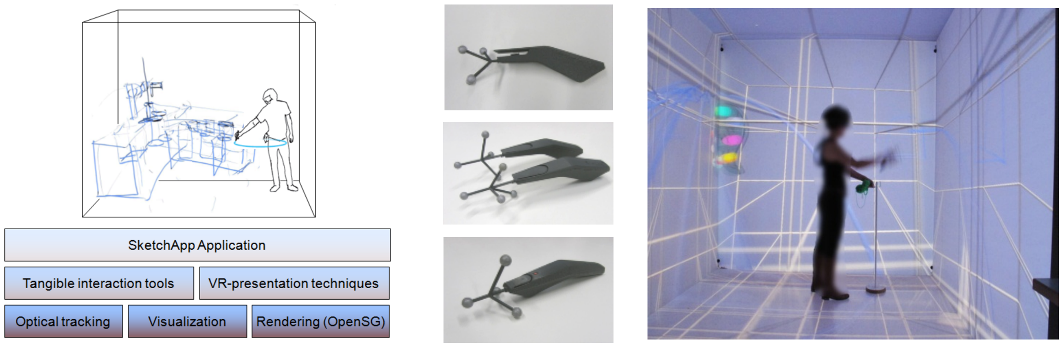
One should note that in order to evaluate the transition between cross-sectional profiles, we require two user defined parameters, namely the number of sample points taken on the cross-sectional profiles n and the number of intermediary profiles generated m. These two values reflect the accuracy of the representation, with the larger values of m and n giving a smoother object representation. This will however incur an increase in the computational time required to generate the model. The designer may set these values according to the level of accuracy required in the 3D representation, however, in order to ensure that a 3D model may be generated without user intervention, the interpretation algorithm may, in the absence of any pre-defined user values, modify the values of m and n adaptively for each part in the annotated drawing.

To determine the value of n, we apply the polygonization algorithm described in [23] to the two cross-sectional profiles, hence representing the two cross-sectional profiles will be represented by straight line segments. This will give an indication on the distance between salient points on the cross-sectional profiles and so, we use the length of the smallest line segment of the two profiles as an indication of a suitable sampling interval, hence determining the number of samples n required to obtain a smooth representation of the cross-sectional profiles. The value of m is determined in a similar manner, but the polygonization algorithm is applied to the scribbled object profile segments instead of the cross-sectional profiles.

3.4 Offline sketching modality

Using this modality, the user sketches the object using the prescribed sketching language, using real pen-and-paper of a graphics tablet as a sketching medium, scanning, or saving the sketch as an image for processing. In order to enable the interpretation algorithms to distinguish the longitudinal sketch and the cross-sectional profiles, the user is required to sketch the two parts of the sketch using different pen colours. The user is not restricted to any two particular colours, but the pen colours selected should have sufficient contrast such that it is easy to distinguish between them, for example, red/pink and green/blue. To distinguish between the two colours, the image is initially converted to a grey-scale image and binarised such that only the ink strokes are retained. The RGB values of these ink strokes are then grouped into two clusters, creating two copies of the image corresponding to the two different colours. The cluster that contains one single connected component can be identified as the longitudinal sketch, while the other will contain the cross-sectional profiles.

Once the 3D geometry of the object is inferred from the sketch, this is shown as 3D model on



(a) (b) (c)

Figure 3: (a) The immersive environment available at Fraunhofer IPK. (b) The tangible interfaces for immersive sketching and modelling: a pliers tool (top); a two-handed Bezier tool (middle) and a pen-stylus (bottom) (c) A user drawing Bezier curves using the two-handed tool [12].

the computer monitor, where the user can use the mouse to rotate the object and it can also be transferred onto the immersive screen via a USB drive, providing for greater interaction with the object.

3.5 Online sketching modality

The online sketching modality was developed using the immersive environment tools available at the Fraunhofer IPK, summarised in Figure 3 [12]. This consists of an immersive screen coupled with a head tracking device and tangible interface tools which allow the user to interact with the virtual 3D objects displayed in the screen. Of particular importance in this setup, the head tracking device allows the user to view the 3D model from different angles while the virtual ink and pliers tool allow the user to sketch, grab and move the 3D object.

Since the sketch is being drawn in an online manner, and the nature of the sketching language requires that the user draws the longitudinal profile first in order to obtain a reference against which the annotated cross-sectional profiles are sketched, the sketch interpretation can use the temporal information to distinguish between the longitudinal sketch and the cross-sectional profiles. Thus, using the online modality, the user is not required to use different pen colours to sketch the longitudinal profile and the cross-sectional profiles using different colours. However, colours are introduced by the interface as a form of feedback, changing the colour of the longitudinal profile from green to red, providing visual feedback to the user, indicating that the sketched strokes have been interpreted correctly by the system. The pen colour then switches automatically to the default green, allowing the user to sketch the cross sectional profiles, such that the completed sketch will consist of a red longitudinal profile and green cross sectional profiles, as shown in Figure 4. In Figure 5, a user is using the pliers tool to interact with the 3D model in the CAVE environment, zooming into the object such that the user appears to be inside the 3D model.

4 USER EVALUATION

The success of an SBI depends on whether users are willing to engage with the SBI and for this, the SBI must be appealing to the user in terms of useability and functionality. In this case, the user must find motivation and practical use for both the online sketching modality as well as the offline sketching modality for the SBI to be accepted as a hybrid SBI. The user evaluation therefore seeks to understand if both sketching modalities are accepted by the user, and in cases

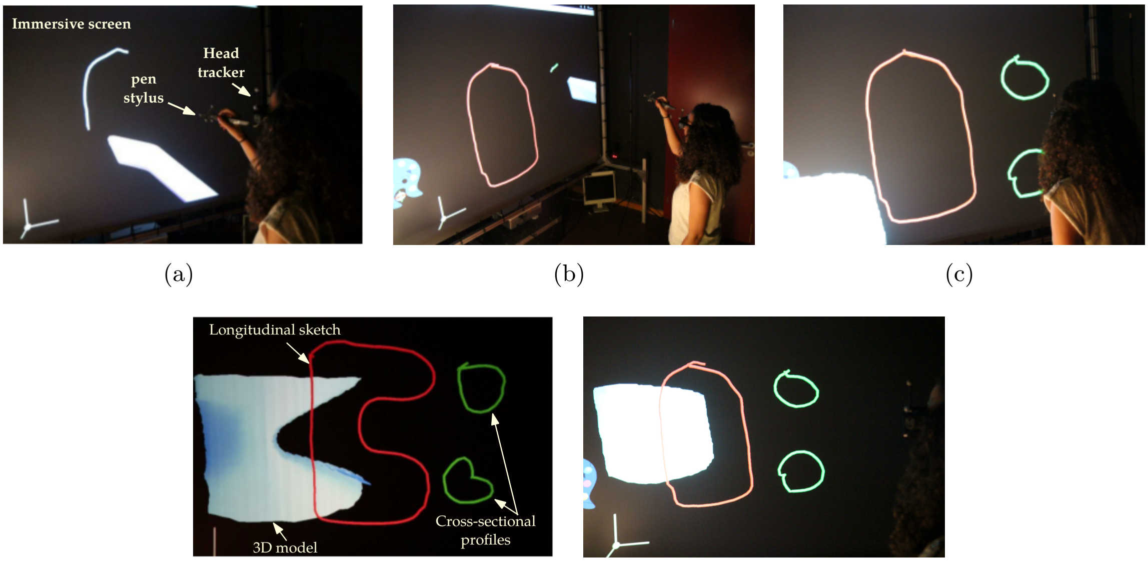


Figure 4: Sketching in the immersive setup. (a) The user is seen drawing the longitudinal profile using the stylus pen. (b) Once finished, the sketched longitudinal profile turns to red, showing it has been correctly recognized. (c) The user then sketches the cross-sectional profiles which turn green once completed. (d, e) Two examples of the complete sketch and corresponding 3D object displayed onto the immersive screen. After drawing the sketch, the 3D virtual model is displayed in blue. This can be then rotated as needed by the user using the plier tool.

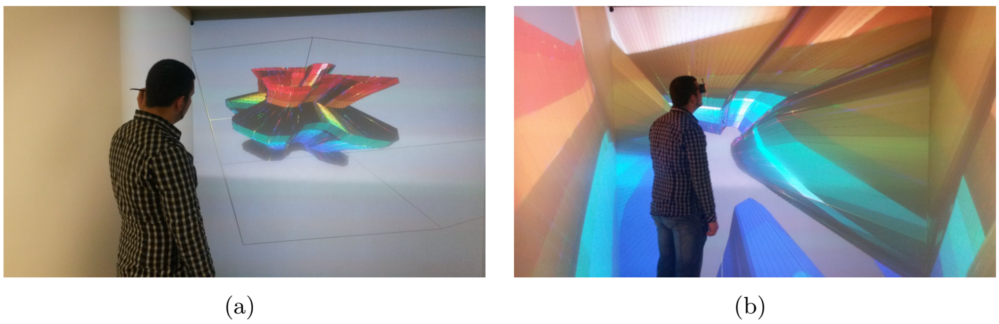


Figure 5: (a) Viewing a 3D model within the CAVE and (b) zooming into it such that the user appears inside the model

where an immersive system is unavailable, whether users would also be satisfied by using the offline sketching modality, with the possibility of displaying and interacting with their results in the immersive environment at some later stage.
To this extent, we asked eight test subjects to try the SBI. These test subjects were presented with four different sketches, shown in Figure 6, which had to be copied in order to obtain a 3D model from each sketch. The sketches were drawn twice, once using the online sketching modality and once using the offline sketching modality, resulting in a total of eight sketching tasks for each user. The subjects included two females and six males whose age ranged between 21 and 36. Five of the subjects are engineers, two are computer scientists and one, a human factor expert.
In order to ensure that the order of presentation does not affect the outcome of the result of the user evaluation, four subjects were presented with the offline sketching modality first, followed by the immersive sketching modality, while the remaining four subjects were presented with the immersive modality followed by the offline modality. For practical reasons, in the

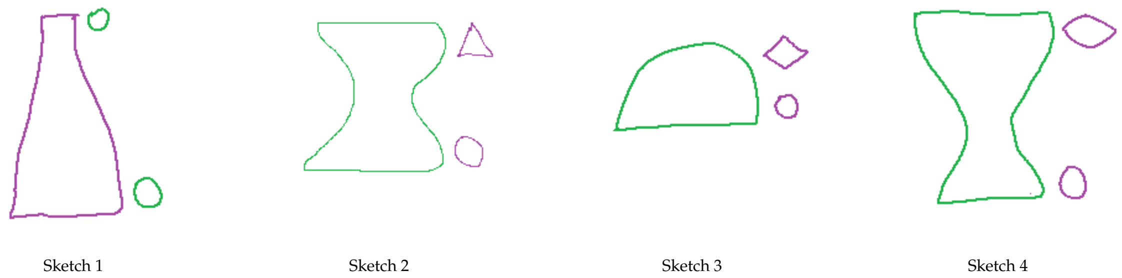


Figure 6: The annotated sketches presented to the users to copy. These sketches test the 3D model generation with different longitudinal profiles and different cross-sectional profiles.

offline sketching modality, subjects were given a Genius G-Pen 450 drawing tablet [24] in lieu of traditional pen-and-paper. The resulting sketch was then saved as an image and processed, with the final 3D model being displayed on the same immersive screen used for the online sketching modality. Before drawing the actual sketches, the users were given time to familiarize themselves with the sketching interfaces and after completing the sketching tasks in each modality, subjects were asked to fill in a questionnaire about their experience and the usability of the system. The time during which the users were engaged in sketching was also recorded.

4.1 The Questionnaire

In order to determine how the users respond to the SBI, we made use of the AttrakDiff questionnaire [25], which consists of a number of 7-point items with bipolar verbal anchors. This provides a semantic differential scale which is a rating scale that is able to indicate the attitude of the user towards the interactive system at use. It is set in a way that allows us to evaluate not only the pragmatic functional quality of the system, but also the hedonic aspects of the system, providing measures for the user stimulation, identification with the system and its attraction [25].

The pragmatic quality (PQ) refers to the usefulness and usability of the system and can be measured by asking the user to scale the system in terms of it being human-centric or computer-centric; simple or complicated; and confusing or clear amongst others. The hedonic quality of stimulation (HQS) relates to the personal need to develop oneself and gain new skills and knowledge. This is measured by asking the user to rank the system on a scale of original to typical; standard to creative. The identification quality (HQI) refers to the user's identification with the system, giving an indication of how well the system communicates important personal values to the user. The user identification can be measured by ranking the system on a scale of professional to amateurish; cheap to valuable among others. The attraction quality ($ATTR$) of the system will give an indication of whether the users had an overall pleasing interaction with the system. This can be measured by asking the user to rank the system on a scale of likeable to unlikable; and ugly to beautiful [25].

The questions posed in the questionnaire therefore provide an insight on the overall user experience of the system and give an indication of whether a user would likely engage with the system again. In order to be considered useful to users, the proposed hybrid sketch-based interface must have an above average ranking in the pragmatic, hedonic and attractive qualities, for both the offline sketching modalities and the online sketching modalities, implying that users would find both modalities useful and practical.

Table 1: Average user responses to the questionnaire results for the pragmatic qualities (PQ), hedonic qualities of identification (HQI) and stimulation (HQS) and the overall hedonic quality (HQ) and attractiveness (ATTR) of the two sketching modalities, giving also the overall mean (μ) and standard deviation (σ) of the user responses.

	Online sketching modality					Offline sketching modality				
User	PQ	HQS	HQI	HQ	ATTR	PQ	HQS	HQI	HQ	ATTR
1	3.57	5.86	4.86	5.36	5.00	3.57	6.00	5.43	5.71	4.71
2	5.29	6.00	5.43	5.71	6.14	5.14	6.00	4.43	5.21	6.57
3	3.71	5.14	5.29	5.21	5.14	3.29	4.71	4.43	4.57	4.29
4	4.00	5.43	5.00	5.21	5.43	5.00	2.57	3.71	3.14	3.57
5	5.57	5.29	5.43	5.36	5.86	5.14	5.71	5.00	5.36	5.86
6	5.29	4.71	4.43	4.57	4.86	4.29	4.43	4.29	4.36	4.57
7	4.29	5.14	3.57	4.36	5.43	1.29	3.57	2.14	2.86	1.71
8	6.43	4.71	5.86	5.29	6.14	5.71	2.14	5.86	4.00	6.14
μ	**4.77**	**5.29**	**4.98**	**5.13**	**5.50**	**4.18**	**4.39**	**4.41**	**4.40**	**4.68**
σ	**1.02**	**0.47**	**0.71**	**0.45**	**0.5**	**1.44**	**1.52**	**1.14**	**1.03**	**1.57**

5 RESULTS AND DISCUSSION

Table 1 gives the mean and standard deviation of the user responses for the pragmatic, hedonic and attractive qualities of the system (refer to Appendix for a graph with individual questionnaire results). Since the questionnaire made use of a 7-point scale, the results in Table 1, show that the user response to the two sketch modalities is above-average, indicating that the users responded well to both sketch modalities.

The average results shown in Table 1 show that the test subjects gave a higher ranking to the hedonic qualities of both sketching modalities, indicating that the subjects could identify with and engage well with both sketching modalities while being able to achieve the set goals with both sketching modalities. The lower pragmatic values can be due to the somewhat restricted set of objects that can be currently modelled with the system as well as the limited interaction that can be performed within the immersive environment which were made available in this system. Increasing the interactions could expand the range of objects that can be modelled and hence increase the usability and usefulness of the system.

Table 1 shows that the test subjects gave different ranking to the dimensions posed by the questionnaire to the different sketching modalities. Some differences in the user responses are to a certain extent expected and are due to the different nature of the sketching modalities. For example, when using the online sketching modality, the 3D model could be displayed instantaneously and the user could interact directly with the 3D model whereas in the offline sketching modality required that the generated 3D models were manually passed to the immersive setup via a USB drive, incurring a delay between the completion of the sketch and the display of the 3D model in the immersive environment. Moreover, the lab environment could have made the practical aspect of the offline sketching paradigm, namely that the design concepts can be created when away from the immersive setup while retaining the ability to display and later manipulate these models in the immersive environment, difficult to communicate to the test subjects. Thus, the online sketching modality can be perceived as more practical and less cumbersome than the offline sketching modality.

The different sketching modalities could also affect the hedonic qualities of the two systems. For example, drawing on a graphics tablet is similar to drawing on paper, such that the offline sketching modality may appear to be more identifiable than stimulating, while sketching in

Table 2: Results of the ANOVA at the 95% confidence level, of the user responses on the pragmatic, hedonic and attractive aspects of the two sketching modalities (p-value ≤ 0.05).

	F	p-value
PQ	**0.894**	**0.360**
HQ	**3.392**	**0.087**
HQS	2.533	0.134
HQI	1.441	0.250
ATTR	**1.983**	**0.181**

virtual ink, which has the added difficulty of there being no physical drawing medium may appear to be more challenging than stimulating.

Overall, the above average responses obtained for both sketching modalities, indicates that the users found the online and offline sketching modalities are somewhat interchangeable. The results show that there is a tendency for users to give a higher ranking to the immersive system. For this reason, a one-way ANOVA was performed on the user responses to each of the pragmatic, hedonic and attractive qualities of the two sketching modalities in order to determine whether the difference observed is significant. Table 2 gives the result of this test which shows that there is no statistical significance between the mean user responses to the two sketching modalities. Although the greatest difference is observed in the overall hedonic qualities, the ANOVA shows that there is no statistical difference between the mean user responses to questions on the stimulation and identification hedonic qualities of the two sketching modalities. Thus, although there are some differences between the user responses in the questionnaire, the subjects in this evaluation do not show a significant preference to either sketching modality.

The recorded time taken by the users to complete the four drawing tasks in both sketching modalities are given in Figure 7(a). This shows that the users in general required more time to complete the sketches in the offline sketching modality, with all median times being larger for the offline sketching modality than for the online sketching modality. However, one may note that there is higher variability in the time spent during the offline sketching modality than the online sketching modality, particularly for sketches three and four. This is an indication that the time spent in the offline sketching modality is more user dependent than the online sketching modality. This can in fact be observed in the average time each user spent while sketching in online and offline modes as shown in Figure 7(b). Form this, one may note that while participants 4, 6, 7, and 8 have very little differences in the time spent sketching, participants 2, 3, and 5 spent considerable more time on the offline sketching modality. This is mainly due to the differences in the offline and online nature of sketching. When drawing on the graphics tablet, the user was at liberty to modify the sketch, removing any unwanted parts, modifying others or even redrawing parts of the sketch, as one would typically do when drawing using pen-and-paper. In the online environment however, we adopted the pen-computer interaction typically used in the absence of icons, that is, the ink is interpreted upon pen release, such that the system the digital ink once and as soon as this has been drawn without offering the option to adjust any part of the sketch. Thus any users wanting to make modifications while engaged in the online sketching were not able to through this system.

6 CONCLUSION

In conclusion, this user study showed that this system has both the pragmatic and hedonic qualities which could be further developed into a fully fledged, hybrid sketching interface. By providing the user with more scope for interaction with the sketched objects, the possible geometries that can be created using this hybrid interface can be extended beyond the scope of this user study, increasing the utility and applicability of the SBI. Furthermore, by automating

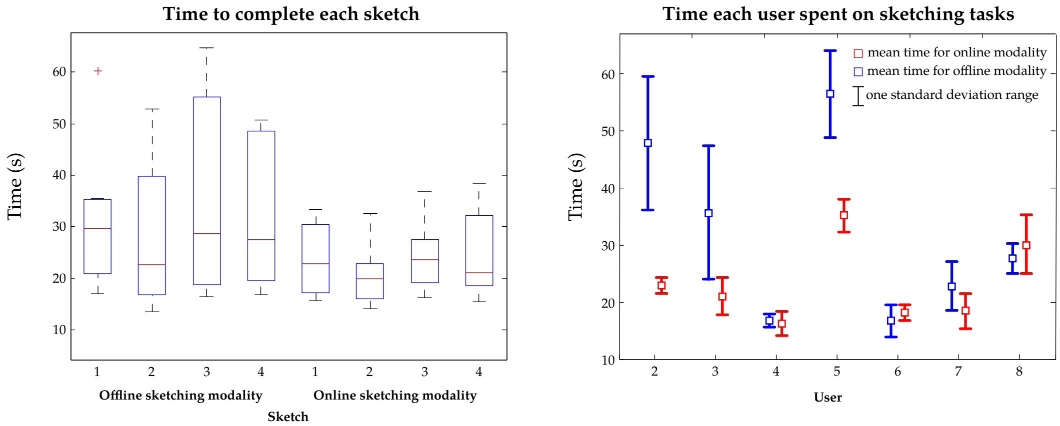


Figure 7: (a) Time spent by the users to complete each sketch (b) The average time and corresponding standard deviation error that each individual user spent on all four sketching tasks in the online and offline modalities. Note that time measurements were available for all but the first user participating in the evaluation study and that even numbered participants started with the online sketching modality followed by the offline sketching modality while odd numbered participants approached the tasks in reverse order.

the transfer of the paper-based sketches into the immersive environment, less effort is required by the user to obtain the 3D models when sketching in the offline modality, allowing the user to take advantage of an input modality with which the user can already identify with.
The results obtained from this user study are encouraging and show that it is possible to integrate offline and online sketching modalities, while retaining a system that has pragmatic and hedonic qualities. Moreover, this study shows that users can be given the flexibility to choose their preferred sketching modality without reducing the quality of the generated 3D models.

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Appendix

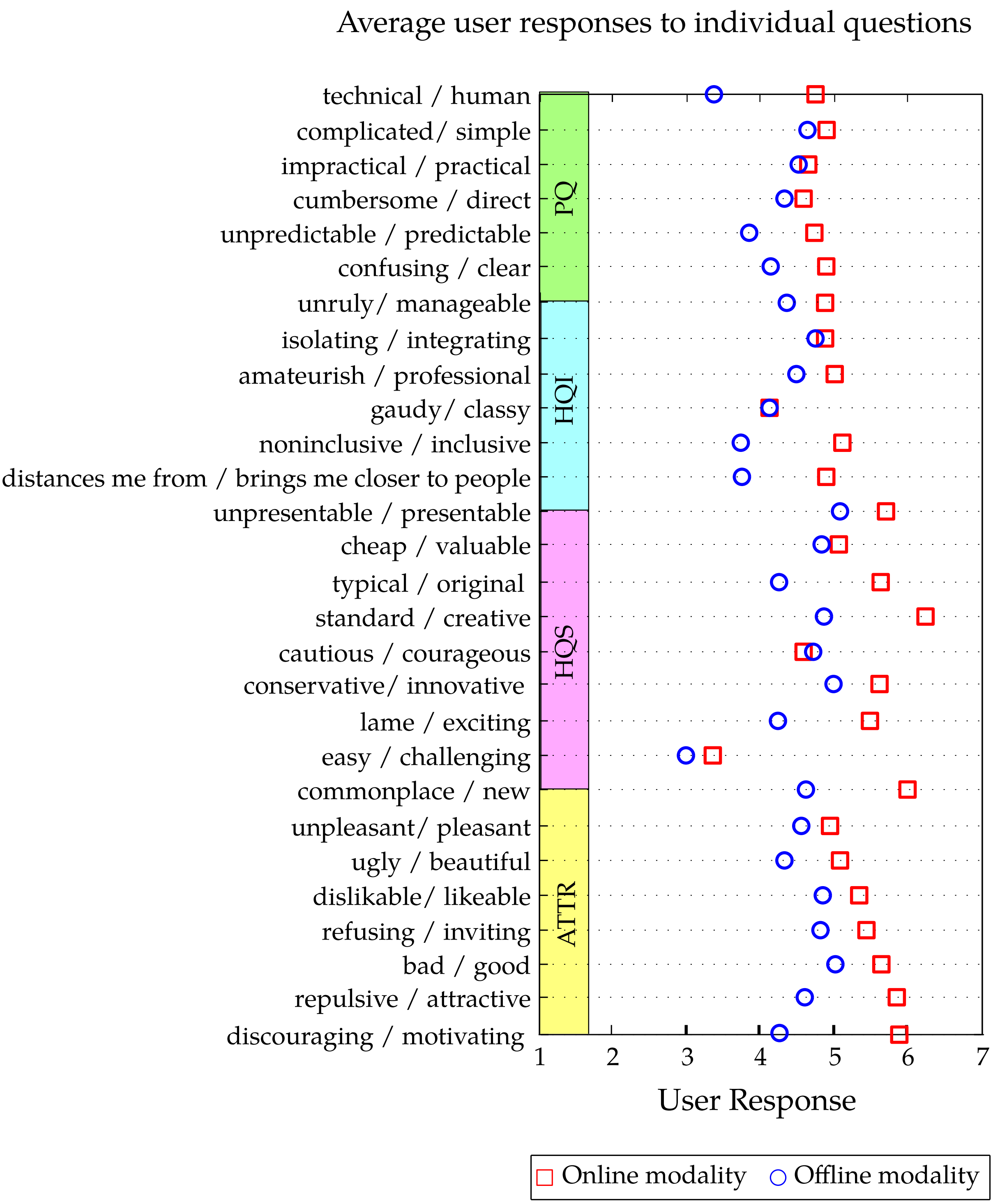

Figure 8: The ordered individual results obtained from the questionnaire.