Investigating User Response to a Hybrid Sketch Based Interface for Creating 3D Virtual Models in an Immersive Environment

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Keywords: Sketch-based Interfaces, Mixed Sketching Environments, Usability Study.

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 paper, 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 (Cook and Agah, 2009) and this can be observed in the shift in computer modelling applications from software such as AutoCAD (AutoDesk Inc, 2014) and CATIA (Dassault Systems, 2014) among others, targeted for engineers and architects to others such as Sketch-Up (Trimble Navigation Limited, 2013) 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 (Cruz and Velho, 2010; Olsen et al., 2011). 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 designers 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 (Cook and Agah, 2009; Schweikardt and Gross, 2000). In addition, since human observers can understand 2D drawings as abstractions of the 3D world, artists can use sketches as effective communications tools (Cruz and Velho, 2010). This is particularly useful in commercial design, allowing the artist to present the client with initial designs before the final construction begins (Cook and Agah, 2009). In modern design 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 (Schweikardt and Gross, 2000), 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 (Eissen and Steur, 2007; Olsen et al., 2009).

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

Bonnici A., Israel J., Muscat A., Camilleri D., Camilleri K. and Rothenburg U..
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DOI: 10.5220/0005320504700477
In *Proceedings of the 10th International Conference on Computer Graphics Theory and Applications* (GRAPP-2015), pages 470-477
ISBN: 978-989-758-087-1

possible (Lai and Zakaria, 2010). Thus, bringing together the sketching flexibility of pen-and-paper sketching with computer-based modelling.

In this paper, we build on the paper-based SBI and immersive modelling environments described in (Bartolo et al., 2008) and (Israel et al., 2013) 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 paper 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 paper.

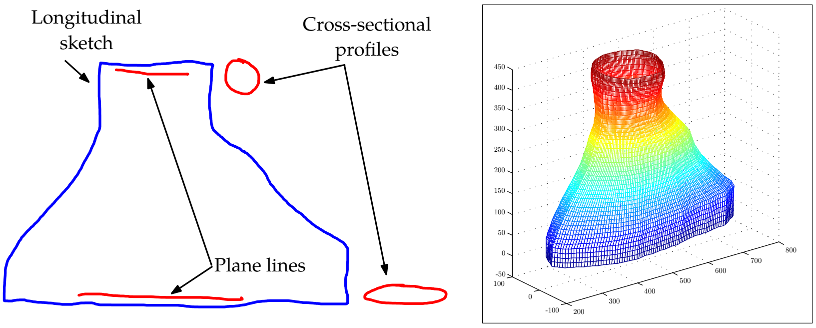
2 RELATED WORK

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 (Zeleznik et al., 2006; Fonseca et al., 2002). 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 (Igarashi et al., 1997) 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 (Igarashi et al., 1999) and SHAPESHOP (Schmidt et al., 2006) 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 (Schweikardt and Gross, 2000) and FIBREMESH (Nealen et al., 2007) providing examples of such interfaces.

These sketching modalities can be extended to introduce fully immersive drawing (Perkunder et al., 2010), (Israel et al., 2013), 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 (Israel et al., 2009). 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 (Wiese et al., 2010).

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., within the immersive environment, thus precluding the use of pen-and-paper sketching. In contrast, Bartolo et al. 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. Using this SBI, the user's sketch is expected to contain two components namely, the sketched longitudinal profile of the object, which defines the object shape, and annotations, which augment the sketch with additional information about the



(a) (b)

Figure 1: (a) Example of a sketch drawn using the sketching language of (Bartolo et al., 2008). (b) The resulting 3D model.

3D geometry of the object. The annotations can be further divided into plane lines and cross-sectional profiles as shown in Figure 1. Cross-sectional profiles are used to define the cross-sectional shape of the object while plane lines are used to indicate the place on the sketch where the cross-sectional profiles should be applied. The user is required to use different colours for the sketch and annotations, allowing the interpretation algorithms to demarcate the sketch from the annotations. Although the cross-sectional profiles define the 3D shape of the object at the plane on which they reside, to create the full 3D model, the object's cross-sectional shape at intermediary planes is required. The cross-sectional shape of the object at these intermediary planes is determined by linearly interpolating the shape of the cross-sectional profiles, while the size and number of intermediary profiles required can be determined from the shape of the longitudinal sketch (Bartolo et al., 2008).

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 of (Bartolo et al., 2008) and the immersive modelling of (Israel et al., 2013) to create a preliminary hybrid SBI that allows for offline and online sketching modalities, using a common sketching language as the sketch input while allowing for a seamless interaction with the completed 3D model.

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 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. The 3D geometry of the object is inferred from the sketch and this can be shown as a static 3D model on the computer monitor or in the immersive screen used in the online sketching modality.

The sketching language required for the sketch is similar to that described in (Bartolo et al., 2008); the user is required to sketch the longitudinal profile of the object in one colour and provide annotations in a different colour. However, we simplify the annotations required by retaining only the cross-sectional profiles and using the centre of moment of the cross-sectional shape to determine the location of the plane which bears this cross-sectional shape, thus rendering the plane lines redundant.

3.3 Online Sketching Modality

The online sketching modality adapts the offline sketching language to an immersive environment. As shown in Figure 2, the setup consists on an immersive

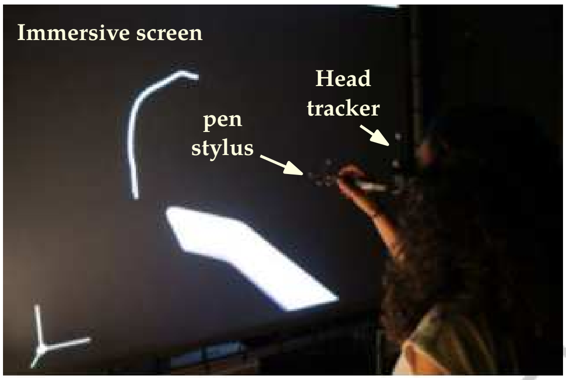


Figure 2: Sketching in the immersive setup. The user is seen here drawing the longitudinal profile using the stylus pen. Once finished, the sketchedlongitudinal profile turns to red, showing it has been correctly recognized.

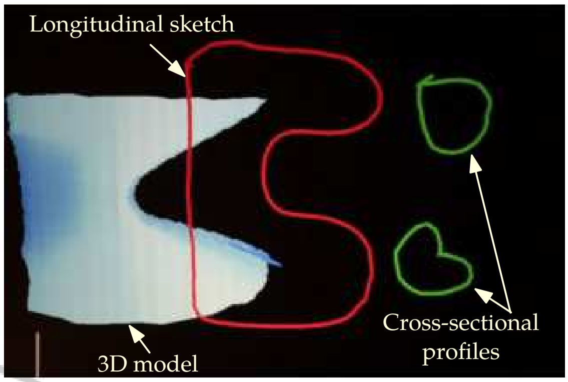


Figure 3: The complete sketch and corresponding 3D screen. After drawing the sketch, the 3D virtual model is displayed in blue. This can be then rotated as needed by the user using the plier tool.

screen together with a head tracking device. This allows the user to observe the complete 3D model from different angles. In this setup, we use two of the tangible interfaces described in (Israel et al., 2013), namely the stylus which allows the user to sketch in virtual ink and the pliers tool which allows the user to 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 annotations 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.

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 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 4, 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 offline sketching modality, subjects were given a Genius G-Pen 450 drawing tablet (Genius G-Pen, 2007) 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

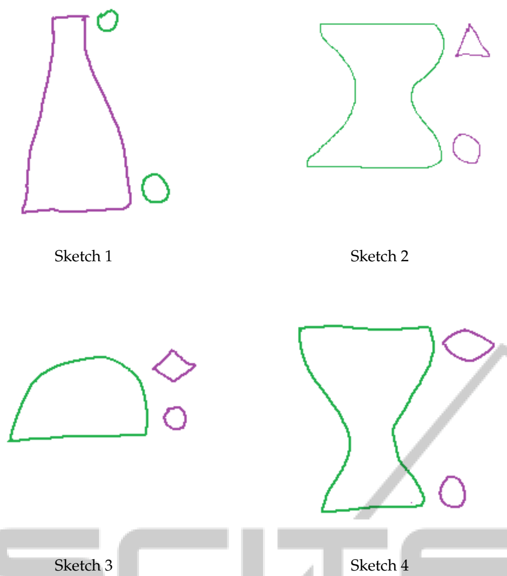


Figure 4: The annotated sketches presented to the users to copy. These sketches test the 3D model generation with different longitudinal profiles and different cross-sectional profiles.

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 questionnare (Hassenzahl, 2008), 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 (Hassenzahl, 2008).

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 (Hassenzahl, 2008).

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 and desirable 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.

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. 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 modelled with the system as well as the limited interaction that can be

Table 1: Average user responses μ 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 standard deviation (σ) of the user responses.

	PQ	HQS	HQI	HQ	ATTR
Online sketching modality					
μ	4.77	5.29	4.98	5.13	5.50
σ	1.02	0.47	0.71	0.45	0.5
Offline sketching modality					
μ	4.18	4.39	4.41	4.40	4.68
σ	1.44	1.52	1.14	1.03	1.57

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. 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 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.

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.

	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**

The recorded time taken by the users to complete the four drawing tasks in both sketching modalities are given in Figure 5(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 5(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, hy-

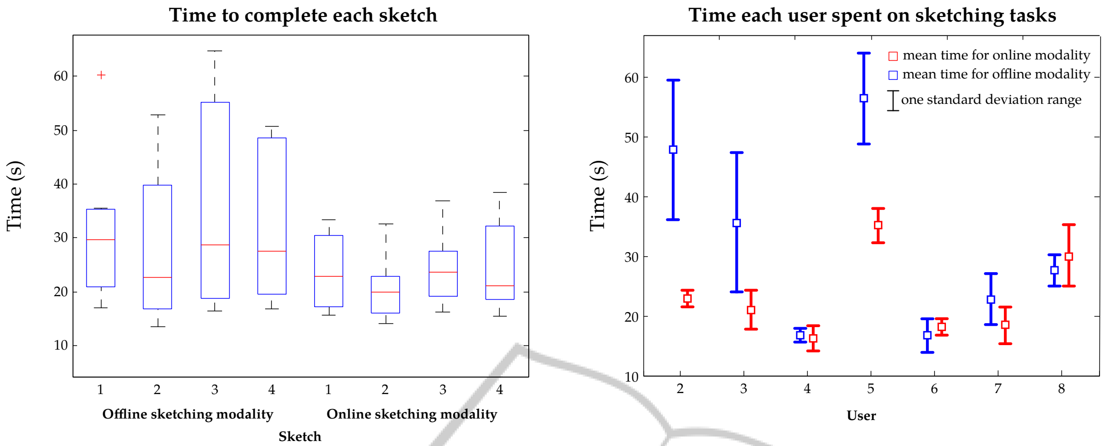


Figure 5: (a) Time spent by the users to complete each sketch. (b) The average time and corresponding standard deviation error that each individual user spent on all four sketching tasks in the online and offline modalities. Note that time measurements were available for all but the first user participating 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.

brid 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 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.

ACKNOWLEDGEMENTS

This research was done in collaboration with the Fraunhofer Institute for Production Systems and Design Technology Berlin. It was supported by VISIONAIR, a project funded by the European Commission under grant agreement 262044.

REFERENCES

AutoDesk Inc (2014). Autocad. http://www.autodesk.com/ products/autocad/overview. Last Accessed: 08-09-2014.

Bartolo, A., Farrugia, P., Camilleri, K., and Borg, J. (2008). A profile-driven sketching interface for pen-and-paper sketches. In *VL/HCC Workshop: Sketch Tools for Diagramming*.

Cook, M. and Agah, A. (2009). A survey of sketch-based 3-d modeling techniques. *Interacting with computers*, 21:201–211.

Cruz, L. and Velho, L. (2010). A sketch on sketch-based interfaces and modeling. In *Graphics, Patterns and Images Tutorials (SIBGRAPI-T), 2010 23rd SIBGRAPI Conference on*, pages 22–33.

Dassault Systems (2014). Catia. http://www.3ds.com/ products-services/catia/. Last Accessed: 09-12-2014.

Eissen, K. and Steur, R. (2007). *Sketching. Drawing Techniques for Product Designers*. BIS Publishers.

Fonseca, M. J., Pimentel, C., and Jorge, J. A. (2002). Cali: An online scribble recognizer for calligraphic interfaces. In *Sketch Understanding, Papers from the 2002 AAAI Spring Symposium*. Citeseer.

Genius G-Pen (2007). Australia products review and rating website. http://www.reviewproduct.com.au/ genius-g-pen-450-graphics-pad/. Last Accessed: 10-12-2014.

Hassenzahl, M. (2008). The interplay of beauty, goodness, and usability in interactive products. *Hum.-Comput. Interact.*, 19(4):319–349.

Igarashi, T., Matsuoka, S., Kawachiya, S., and Tanaka, H. (1997). Interactive beautification: a technique for rapid geometric design. In *UIST '97: Proceedings of the 10th annual ACM symposium on User interface software and technology*, pages 105–114, New York, NY, USA. ACM.

Igarashi, T., Matsuoka, S., and Tanaka, H. (1999). Teddy: A sketching interface for 3d freeform design. In *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH

’99, pages 409–416, New York, NY, USA. ACM Press/Addison-Wesley Publishing Co.

Israel, J., Wiese, E., Mateescu, M., Zllner, C., and Stark, R. (2009). Investigating three-dimensional sketching for early conceptual designresults from expert discussions and user studies. *Computers & Graphics*, 33(4):462 – 473.

Israel, J. H., Mauderli, L., and Greslin, L. (2013). Mastering digital materiality in immersive modelling. In *Proceedings of the International Symposium on Sketch-Based Interfaces and Modeling*, SBIM ’13, pages 15–22, New York, NY, USA. ACM.

Lai, C.-Y. and Zakaria, N. (2010). As sketchy as possible: Application programming interface (api) for sketch-based user interface. In *Information Technology (IT-Sim), 2010 International Symposium in*, volume 1, pages 1–6.

Nealen, A., Igarashi, T., Sorkine, O., and Alexa, M. (2007). Fibermesh: Designing freeform surfaces with 3d curves. *ACM Trans. Graph.*, 26(3).

Olsen, L., Samavati, F., and Jorge, J. (2011). Naturasketch: Modeling from images and natural sketches. *Computer Graphics and Applications, IEEE*, 31(6):24–34.

Olsen, L., Samavati, F. F., Sousa, M. C., and Jorge, J. A. (2009). Sketch-based modeling: A survey. *Computers & Graphics*, 33(1):85 – 103.

Perkunder, H., Israel, J. H., and Alexa, M. (2010). Shape modeling with sketched feature lines in immersive 3d environments. In (Eds.), E. Y.-L. D. . M. A., editor, *ACM SIGGRAPH/Eurographics Symposium on Sketch-Based Interfaces and Modeling SBIM10*, page 127134.

Schmidt, R., Wyvill, B., Sousa, M. C., and Jorge, J. A. (2006). Shapeshop: Sketch-based solid modeling with blobtrees. In *ACM SIGGRAPH 2006 Courses*, SIGGRAPH ’06, New York, NY, USA. ACM.

Schweikardt, E. and Gross, M. D. (2000). Digital clay: deriving digital models from freehand sketches. *Automation in Construction*, 9(1):107 – 115.

Trimble Navigation Limited (2013). Sketchup. http://www.sketchup.com/. Last Accessed: 08-09-2014.

Wiese, E., Israel, J. H., Meyer, A., and Bongartz, S. (2010). Investigating the learnability of immersive free-hand sketching. In *Proceedings of the Seventh Sketch-Based Interfaces and Modeling Symposium*, SBIM ’10, pages 135–142, Aire-la-Ville, Switzerland, Switzerland. Eurographics Association.

Zeleznik, R. C., Herndon, K. P., and Hughes, J. F. (2006). Sketch: An interface for sketching 3d scenes. In *ACM SIGGRAPH 2006 Courses*, SIGGRAPH ’06, New York, NY, USA. ACM.