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Sketch-Based Interfaces and Modeling (SBIM)

Investigating three-dimensional sketching for early conceptual design—Results from expert discussions and user studies

J.H. Israel [a,*], E. Wiese [b], M. Mateescu [b], C. Zöllner [c], R. Stark [a]

[a] Division Virtual Product Creation, Fraunhofer Institute for Production Systems and Design Technology IPK, Pascalstrasse 8-9, 10857 Berlin, Germany
[b] Centre of Human-Machine-Systems, Technische Universität Berlin, Germany
[c] Institute for Product and Process Design, The Berlin University of the Arts, Germany

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ABSTRACT

As immersive 3D user interfaces reach broader acceptance, their use as sketching media is attracting both commercial and academic interests. So far, little is known about user requirements and cognitive aspects of immersive 3D sketching. Also the latter's integration into the workflow of virtual product development is far from being solved.

We present results from two focus group expert discussions, a comparative user study on immersive 3D sketching conducted among professional furniture designers and a qualitative content analysis of user statements. The results of the focus group discussions show a strong interest in using the three-dimensional (3D) space as a medium for conceptual design. Users expect it to provide new means for the sketching process, namely spatiality, one-to-one proportions, associations, and formability. Eight groups of functions required for 3D sketching were outlined during the discussions.

The comparative study was intended to find and investigate advantages of immersive three-dimensional space and its additional degrees-of-freedom for creative/reflective externalization processes. We compared a 3D and a 2D baseline condition in the same technical environment, a VR-Cave system. In both conditions, no haptic feedback was provided and the 2D condition was not intended to simulate traditional 2D sketching (on paper). The results from our user study show that both the sketching process and the resulting sketches differ in the 2D and 3D condition, namely in terms of the perceived fluency of sketch creation, in terms of the perceived appropriateness for the task, and in terms of the perceived stimulation by the medium, the movement speed, the sketch sizes, the degree of detail, the functional aspects, and the usage time. In order to validate the results of the focus group discussions, we produced a questionnaire to check for the subjectively perceived advantages and disadvantages in both the 2D and 3D conditions. A qualitative content analysis of the user statements revealed that the biggest advantage of 3D sketching lies in the sketching process itself. In particular, the participants emphasized the system's ability to foster inspiration and to improve the recognition of spatiality and spatial thinking.

We argue that both 2D and 3D sketching are relevant for early conceptual design. As we progress towards 3D sketching, new tangible interactive tools are needed, which account for the user's perceptual and cognitive abilities.

1. Introduction

Whereas immersive three-dimensional (3D) sketching is subject to academic research and industrial applications, little is known about its real benefit compared to two-dimensional (2D) sketching or other means of conceptual design such as physical modelling, the use of CAD systems or even gesturing [1].

Sketches are usually the first visual product models that designers create by *externalizing* their mental models and concepts of the product. But, as Suwa and Tversky [2,3] point out, sketching is not only about externalizing pre-existing mental models. Rather, designers develop their ideas while sketching and discover new links and approaches for new product features (reflecting-in-action [4], Fig. 1). During the product creation process, sketches are essential in the product planning and task clarification phases (finding and choosing product ideas), the conceptual phase (specifying principal options) and the embodiment design phase (preliminary design, choosing proper variants, detailed design) [5,6]. Besides CAD models, sketches on paper are still the most important product models in early design

* Corresponding author. Tel.: +49 30 39006 275; fax: +49 30 3930246.
E-mail addresses: johann.habakuk.israel@zmms.tu-berlin.de, johann.habakuk.israel@ipk.fraunhofer.de (J.H. Israel).
URL: http://www.ipk.fraunhofer.de (J.H. Israel).

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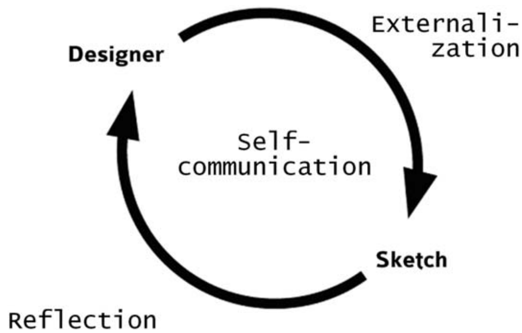

Fig. 1. Sketching as a process of externalization, reflection and self-communication.

phases: 60 percent of all drawings made during product design are sketches [7], 80 percent of the time spent writing or tracing solutions is used for creating sketches [8] and the ratio of creation time compared to utilization is much higher for paper sketches (3:1) than for technical drawings (1:1) [9]. In a study with 66 designers and engineers, Römer [10] found that sketches are used particularly frequently with CAD systems. In the studies, almost all participants utilized sketches in early design phases. Sketching on paper seems to offer functionalities that cannot be provided by CAD systems, e.g. externalization speed, high visual resolution, and instant visual feedback.

The core properties of sketches according to Buxton [11] are that they are quick, inexpensive, disposable, plentiful, that they have a clear vocabulary, minimal detail, and that they are ambiguous and suggest as well as explore solutions rather than confirm them. In comparison, physical tools are more widely used and relevant than digital ones. This is usually ascribed to the delay and low resolution of the digital systems, which slow down the self-communication process and hinder designers wishing to draw and think concurrently [10,12].

2. 3D sketching

In reflective self-communication processes such as sketching, the actual medium determines many of the properties and affordances an external image or model provides. Virtual environments are a new medium and as such are very likely to influence the sketching process. 3D visualizations, for example, have advantages for solving basic tasks [13]. For various reasons we expected an immersive 3D medium to be more appropriate for externalizing visual mental models than a 2D medium would be. For example, 3D environments would allow designers to move within their drawing, they would not require mental projection of 3D product models onto 2D planes and they could provide more cues for the self-communication process.

3D sketching and drawing systems for immersive VR systems have become increasingly popular. Some systems use plain hand gestures as "input" (e.g. [1,14]), some employ freehand tools for the generation of visually rich and aesthetic sketches and paintings (e.g. [15,16]). Other solutions focus on the creation of advanced CAD-like free-form curves and surfaces (e.g. [17]) or generate exact surfaces and solid geometries by automatically recognizing basic object patterns from hand-drawn sketches [18–20]. Hybrid solutions, which seamlessly integrate two-dimensional input on LCD touch-screens and 3D visualization on auto-stereoscopic desktop screens, have been shown to enable fluent creative sketching [21].

Much research was done in the area of haptic-aided input techniques for immersive sketching and modelling. In a study with industrial designers, Sener et al. [22] found that physical feedback is helpful for understanding the form and texture qualities of virtual objects during immersive modelling tasks. Raymaekers et al. [23] utilized haptic feedback for controlling the width of sketched curves and for providing editing and erasing functions. In a comparative study, Keefe et al. [24] investigated the effects of haptic support in one- and two-handed 3D sketching modes. They found that interaction techniques that simulate tape-like or slowed drawing (drag) help to improve the accuracy of 3D drawings, but require longer sketching times (speed-accuracy trade-off). Keefe et al. found also that augmenting freehand drawing with simple haptic friction effects does not considerably improve sketch quality.

3. Focus group expert discussion

In an effort to investigate the potentials and limitations of 3D sketching in immersive virtual environments for conceptual design, i.e. whether 3D virtual space is an adequate and supporting sketching medium, and in order to derive user requirements regarding functionality of and tools for such systems, we chose a qualitative research approach.

In five individual interviews with design experts we investigated the field of product design and sketching and created a semi-structured guideline, which included open research questions to be addressed in follow-up focus group interviews (see [25] for a description of the focus groups and [26] for an example).

3.1. Subjects

We conducted two focus group interviews among 14 design experts from the fields of furniture design and interior design. Their shape-defining product models, which might benefit most from 3D sketching, bear most of the product characteristics. Sketches are the major design tools during the early conceptual phases. Taking part were three university professors, three interior designers, three architects, three product designers and two mechanical engineers, with an average of 11.6 years professional experience. Participants received an expense allowance.

3.2. Procedure

Both focus group sessions were led by two moderators who had little influence on the content of the discussion but intervened whenever it was about to lose focus. The sessions lasted 2.5 h and were videotaped, one moderator took hand-written minutes. Prior to the expert focus group interviews the moderators conducted two test sessions with design students and post-graduates in order to develop moderation skills and the guidelines.

After a short introduction, participants answered and discussed questions related to "sketching and furniture design". In this starting phase, each expert had enough time to introduce his or her own design approach. Questions then addressed the tasks in early phases of product design, the functionality of sketching and sketches, and the use of tools. A video collage of 3D furniture sketching was then shown as a stimulus [27]. Questions following the video session addressed possibilities and limitations of 3D sketching and differences as well as commonalities of 2D and 3D sketching. At the end of both focus group sessions, participants were asked to summarize their ideas and to write down their favourite 3D sketching functions on cards. These were put on pin