Sketching with Digital Pen and Paper

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Abstract: Architectural sketching with the computer has been possible for some time now. Using manual and optical digitizers architects have been able to create images similar in structure and appearance to conventional sketches on paper. Digitized sketches are traditionally associated with early design but are also increasingly linked to interactive interfaces and information management. The paper reports on the application of a new technology (Anoto) that uses a digital pen on specially prepared paper. The focus of the application was feedback from analogue documents to the computer programs used for preparing these documents and on the roles of freehand sketching in later design phases. Sketching with digital pen and paper was found to be useful for the management of annotations made on analogue versions of digital information, especially in multi-actor synchronous and asynchronous situations.

1 SKETCHING AND THE COMPUTER

Architects have been making and processing sketches with computers for some time now, even though in many respects sketching looks like an afterthought in design automation. Freehand sketching with the computer has developed in the margins of CAD hardware. The combination of graphics tablets with pen-like pointing devices has provided the basic means for manually digitizing drawings. Manual digitizers are characterized by low user threshold, as their mechanical and ergonomic properties are similar to these of familiar analogue media (Woessner, Kieferle, and Drosdol 2004, Lim 2003). Arguably more important for the transfer of analogue images to the computer have been optical digitizers (scanners), which produce pixel images. This makes optical digitization less attractive for several applications but in terms of utility scanners provide more flexibility, tolerance and ease. They accept a wider variety of analogue documents and hence allow the user to make full use of analogue skills – as opposed to the weaknesses of manual digitizers in mechanical aspects of sketching, i.e. the interaction of the drawer's anatomy with furniture and drawing materials (Van Sommers 1984). Manual digitizers also exhibit limitations in terms of cognitive ergonomics. For example, sketching with most tablets involves constantly looking away from the hand and frequent interruptions for giving commands. Most attempts to alleviate such problems combine the functionalities of the graphics tablet with those of the monitor (e.g. tablet PC, palmtop).

The quality of the digital images produced by either optical or mechanical devices is adequate for most tasks. Digitization is particularly successful in the *paradigmatic* dimension, i.e. the graphic components of a drawing. These are normally registered with an accuracy and precision that allow for high legibility and extensive digital processing. On the other hand, the *syntagmatic* dimension, i.e the sequential creation of the drawing, remains rather elusive. This is less due to technological limitations and more because of the lack of specific, focused requirements. When available the ability to record and play back strokes is frequently neglected as a gimmick.

Sketching is generally associated with early, conceptual design. The development of early design tools has relied heavily on sketching input (Do 2001), while the transfer of a sketch to the computer generally concerns the transformation into measured drawing or 3D model (Jozen, Wang, and Sasada 1999). Consequently, the emphasis has remained on the paradigmatic dimension (Koutamanis 2001), the symbolic content of the sketch and digitization quality. The paradigmatic dimension has also provided inspiration and means for abstract symbols, generative actions and manipulations in interactive interfaces for digital environments (Do 2001, Achten and Jessurun 2002), as well as for visual indexing and retrieval (Do 2002).

In recent years freehand sketches have started receiving attention beyond the early design phases, mostly thanks to new approaches to information integration and collaborative design. These have led to a number of tools and digital environments where sketches play several roles. Internet collaboration environments make extensive use of freehand sketching for annotating digital documents, e.g. in markup and redlining in CAD document viewers or whiteboarding. Some environments go even further and recreate the architect's analogue workplace also with respect to visual information management, including sketches and freehand annotations. Similar transfers of analogue environments also underlie interactive visualization or 3D modelling. In the resulting compound environments freehand sketching is an attractive option for interaction because of its apparent simplicity (Lim 2003): it makes interfaces more compact because of familiarity with the interaction metaphor.

The significance of using sketching beyond the purposes of early generative activities is also acknowledged in cyclical models of visual thinking, such as the ARC (act-reflect-change) cycle and the ETC (express/test cycle) model. Such models stress something that architects and designers already know but possibly do not fully appreciate: reflection, testing and modification of a design are all served by sketches and freehand annotations. In architecture, design and engineering "sketches and drawings are the basic components of communication; words are built around them" (Henderson 1999). The complex, weakly structured or even chaotic "muddling through" in explorations of divergent approaches and solutions that characterize the early phases form a mode that continues to be applicable throughout the design process, especially in analysis and revision. A main difference is that early phases tend to keep precedents implicit and give the impression of starting from scratch, while later phases operate against an explicit background of drawings and decisions: Sketching and drawing are also seen as a neutral way of focusing collaborative activities on common tasks and of mirroring the discussions in a group.

2 DIGITAL PEN AND PAPER

The research described in the present paper aims to: (1) explore roles and forms of freehand sketching throughout the design process and in particular in later phases of the design process; and (2) test and adapt new technologies to architectural purposes with particular emphasis on providing feedback from analogue to digital environments. The second aim derives from the realization that much effort has been put into digitizing analogue documents but little has been done to transfer the structure of digital information back to analogue environments. Still, the main purpose of design automation in practice is the production of analogue hard copy: conventional drawings and other design documents. The evolution of a design takes place mostly by means of such analogue documents, including in group sessions and meetings. Many discussions, suggestions and decisions can be traced back in the annotations that "deface" the computer prints. The transfer of these annotations back to the computer records decisions that may be distorted soon after a design session, as well as facilitates a closer correlation between annotation and design entity.

We focused on mobile tools as a simple, unobtrusive means of achieving our goals (Cheng and Lane-Cumming 2003). Such tools are often dismissed as mere gadgets but this simply reflects the way technologies are marketed. In terms of connectivity mobile tools offer significant advantages through the proliferation of GPRS, Wi-Fi and Bluetooth, while their portability and ergonomics have become acceptable for most practical purposes. Moreover, they are widely, affordable, familiar and available also for professional applications. Our choice of digital sketching technology was the Anoto digital pen and paper (http://www.anoto.com). This technology is an alternative to mechanical and optical digitizers, with characteristics that help bridge the gap between the analogue and the digital image, especially in terms of ergonomics and mobility. Anoto pens can write on any kind of paper form, provided the form is covered with a proprietary dot pattern with a nominal spacing of 0.3 mm. The digital pen is equipped with a tiny infrared LED camera of the CMOS image-sensing type. The camera is positioned beside the ballpoint tip and takes 50-100 digital snapshots of strokes made by the pen on the dot pattern within a 7 mm range from the tip. The snapshots are stored in the pen as a series of map coordinates that correspond to the exact location of the strokes (as continuous curves) on the particular page.

The drawings can be transferred (synchronized) to a computer or smartphone using Bluetooth or a USB connection. The digital image produced by synchronization is a precise and exact copy of the analogue drawings made with the pen. In transferring the images the pen also reports on which piece of paper the drawing has been made (including the exact position on the form). This automatic document management allows users to switch between different documents without having to keep track of the changes. Moreover, different forms or documents can be linked to different computer applications, thereby automating post-processing of the images. Post-processing may also include grouping of strokes into higher-level primitives (e.g. OCR). The digital images are not static but can play back the sequence of strokes as they were made on paper. This provides a representation of syntagmatic aspects that is adequate for the identification and analysis of drawing actions (Cheng 2004).

3 MECHANICAL ASPECTS

Initial explorations of sketching with the digital pen and paper inevitably evolved around mechanical aspects. These tend to dominate acquaintance with a new device and with a new technology. Mechanical aspects relate to the interaction of the drawer's anatomy with furniture and drawing materials. The drawer's movements, actions and choices with respect to making a particular (e.g. the starting position for a circle) guide further actions in one or another direction and may underlie consistencies (e.g. in stroke direction) more than culture or nurture (Van Sommers 1984). The digital pen has few differences with normal ballpoint pens. The most striking difference is the thickness of the digital pen: the holding area has a circumference of approximately 60 mm (compared to 30 mm for a pencil or 45 mm for a thick graphite lead holder). Drawers with a preference for thinner writing implements were particularly unhappy with the digital pen. Otherwise the digital pen exhibited few apparent mechanical differences with conventional ballpoint pens. In order to ensure minimal adaptation costs in time and effort we sought test users accustomed to sketching and doodling with a ballpoint pen. We expected that they would have the appropriate tolerances for the evaluation of mechanical aspects.

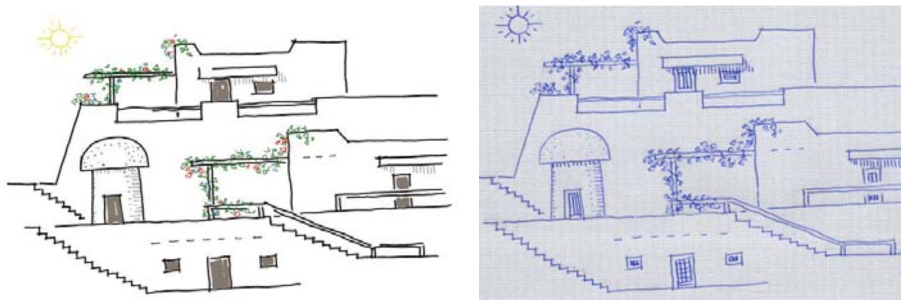

Figure 1 Digital ballpoint sketch (left: digital pen version; right: digital paper)

Drawers were given a minimal instruction and practically no training with the digital pen. We assumed that this would help identify problems and conflicts on the basis of user experiences (as opposed to researchers' expectations). Users were encouraged to synchronize their pen with the computer frequently so as to evaluate the interim states of their sketches. Initial trials looked promising: after mastering the operational basics, users quickly started experimenting with line thickness and colour (Figure 1). The next step involved making use of these pen features for expressing aspects of the scene such as depth (Figure 2). This was generally done in several stages, using synchronization and analysis of the digital image before proceeding with a new element, colour or line weight. However, users were soon to discover the limitations of the digital pen, especially with respect to stroke weight and pen orientation: short, light strokes are poorly captured by the LED camera. Moreover, writing at an angle of less than 60° against the paper means that the camera may fail to capture the strokes. As a result, many sketches failed.

Figure 2 Line weight and colour (left: digital pen version; right: digital paper)

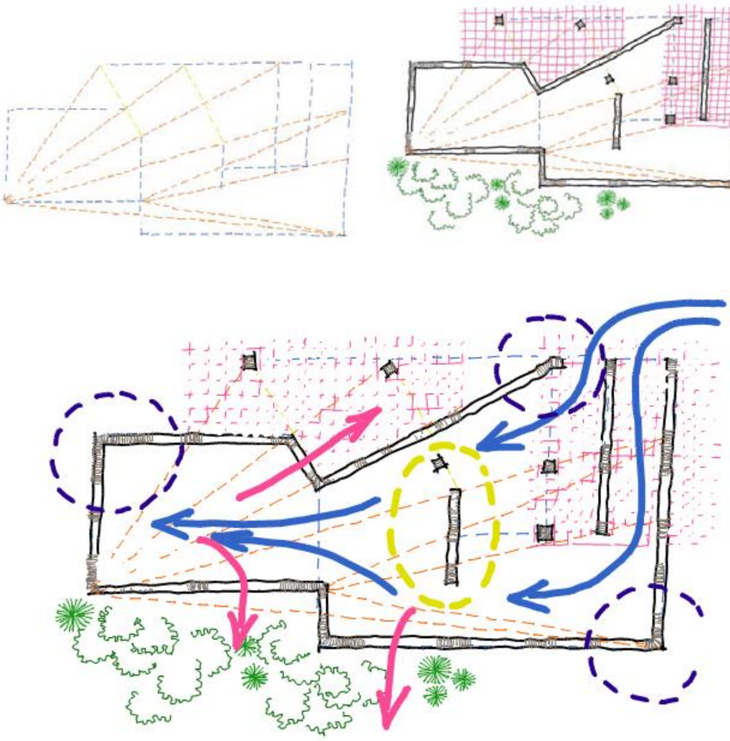

Figure 3 Explanatory sketch (top left: underlying grid; top right: design sketch; bottom: use patterns in design)

Rather than extensively instructing and training the drawers we decided to impose artificial constraints that simplified the technical requirements on the sketches. As the initial failures verified, the digital pen is less appropriate for naturalistic imagery than for more abstract graphics such as orthographic projections and diagrams. Consequently we decided to avoid the usual artistic sketching problems by concentrating on more abstract conventional representations and analytical situations. For example, an architect was asked to explain the principles behind one of her designs, a pavilion based on an irregular grid of dynamic lines. The discussion on the derivation of the form from these lines and on the effects of the form on dynamic aspects such as circulation and orientation made extensive use of multi-layered yet very legible sketches (Figure 3).

4 SYNTAGMATIC ASPECTS

Analytical sketches such as Figure 3 also reinforced our expectation that drawing with the digital pen supports extensive parsing of multilayered, complex sketches. This derives partly from the options given to the user concerning line weight and colour but primarily from the ability to record the syntagmatic dimension. In many cases syntagmatic information adds little to the final product but in complex, ambiguous sketches the ability to trace the moment and the actor may help unravel small mysteries. The sequence of strokes and states of the image in Figure 3 correspond to the narration of the designer and the presentation of the explanation of the design. In a design situation the corresponding sequence would depict the registration of apparent design decisions, including backtracking to and revision of earlier decisions. In order to focus on the syntagmatic dimension we chose to concentrate on later design phases, where the specificity of decisions and products combines with the necessity of continuity, clarity and integration. These phases involve multi-actor situations that make intensive use of compound documents in communication, revision and feedback to earlier decisions, thereby providing examples rich in constraints and requirements for visual information management.

The first challenge in the use of digital pen and paper in later design phases was that it should be used against the background of a variety of design documents and not on empty stationery. This meant that the Anoto dot pattern should be combined with the documents of a particular design. Such combinations can be created by:

1. Including the Anoto dot pattern in the digital documents to be printed
2. Printing or copying documents on Anoto stationary
3. Printing the dot pattern on tracing paper for use on top of other documents

The first solution is the most elegant and efficient but unfortunately use of the proprietary dot pattern involves special licensing and fees. Consequently, we made extensive use of the second solution, employing not only commercially available stationery but also forms we printed on a variety of paper sorts using the PDF files included in the software that is supplied with the digital pen. We used standard laser and inkjet printers with a resolution of 300 and 600 dpi without problems other than that the LED camera of the pen performed poorly in heavily printed areas (Figure 4) where there was insufficient contrast or the dot pattern was obscured by the printed drawing (typically hatched areas). The third solution was welcomed by the drawers because it offered the possibility to use overlay techniques as well as more paper sorts. However, the dot pattern also reduced the transparency of the tracing paper.

Figure 4 Combinations of different aspects in a façade extension study

Even though the pen captures only the new drawing and writing actions, the transfer of the digital sketches to the software used for the production of the drawings simply involved appropriate scaling of the digital images (i.e. reversing the scaling used in printing). The sketches were imported and superimposed on the original documents as overlay pixel images in CAD, as redlining in CAD viewers and as combined background (together with the CAD documents) in whiteboarding. In all cases the alignment of the CAD images and the digital sketches was precise and distortion-free (even though some drawers sketched on their laps or creased the paper while working on a table). We estimated the tolerance of the digital sketches was in the area of 0.5 mm. The high precision of the digital pen also allowed us to combine any number of sketches with the CAD images, which facilitated the analysis of different aspects and the static combination of aspects in multilayered structures (Figure 4).

The analysis of layers and aspects in a sketch refers initially to paradigmatic aspects (form, colour and stroke thickness). However, it came as no surprise that the syntagmatic order largely matched the paradigmatic structure: semantically and visually related graphic components were generally drawn in groups. This simplified distinction between different aspects and permitted a variety of combinations in a manner similar to overlaying: as aspects tended to occupy different segments in the timeline of a drawing we could combine aspects by omitting segments. Mechanical aspects sometimes complicated segmentation because drawers might cluster graphic elements in a mechanically convenient order (e.g. make all strokes with a particular orientation in one go) rather than enter each design entity separately.

Figure 5 Different states in a conversion study involving three drawers

The last application we explored involved the use of digital pens and paper by small groups (3-5 users) in the analysis and further development of existing designs. By issuing each participant with an own digital pen and asking them to synchronize the pens periodically (ostensibly in order to charge the battery) we managed to record different aspects at different states throughout the process without intruding to a disconcerting degree. The pens were used both synchronously and asynchronously. In synchronous situations we promoted the use of tracing paper so that participants could distinguish visually between their respective input. To our surprise, drawers soon abandoned tracing paper in favour of using multiple copies of the same document and combining their input in the computer, similarly to the asynchronous situations. The compactness of the files and their segmentation into different paper forms, actors and aspects offered interesting overlaying opportunities: by making various file combinations we were able to illustrate or reconstruct a particular point of view or a discussion on a specific issue (Figure 5). This was enhanced by the dynamic playback of strokes, which meant that we could recreate a series of actions in the computer files. Document management was straightforward, as the files could be identified by pen, paper form and relative time.

Some of the details that were particularly interesting concerned the emergence of shapes that frequently eluded the participants during the session and were considered with some surprise and even suspicion when the products of the session were reviewed. Accidental emergence was mostly a case of erroneous interpretation of overlapping or adjacent but semantically unrelated strokes made by different drawers or at different times. This was primarily due to relationships of continuity and closure that linked the strokes together in compact or familiar forms. For example, a discussion on the orientation of a free-standing L-shaped wall in a foyer produced a rectangular image that puzzled the participants in the discussion, a couple of whom remembered erroneously that the wall was abandoned in favour of a primitive hut-like pavilion. The ability to distinguish between drawers, the corresponding aspects and states of the process in the syntagmatic order generally cleared up misinterpretations. In a similar fashion we were able to analyse issues of common authorship e.g. trace back the derivation and precedence of design constraints that guided design development.

5 UTILITY AND APPLICABILITY

The digital pen is more of a writing than a sketching tool. It offers less expression possibilities than analogue media or sketching software but larger drawing surfaces than other mobile devices (potentially limited only by the size of printing devices and paper sheets). Ergonomically it is inferior to analogue media and pen-line pointing devices but freehand sketching appears to be more forgiving than writing: holding a pen properly is significant for the readability of handwritten text but drawing is less sensitive, especially with more abstract representations. In terms of design information management the technology is a useful addition with respect to the registration and feedback of annotations on analogue versions of digital documents. Combination of sketches with digital documents is straightforward, precise and efficient – to the extent that it can be performed frequently during a design session. The ability to register and analyse the syntagmatic dimension is a useful means to the interpretation of a sketch, especially with respect to emergence and precedence. The recording of syntagmatic information as a sequence of strokes suffices in most cases: there were few instances where a precise time stamp was desirable. The capabilities of the technology are well suited to the support and analysis of multi-actor situations and group processes. Even though the digital pen and paper are no perfect sketching tools, their functionality comes so close to that of conventional analogue media that the group sessions could take place without unnecessary interruptions for technical reasons. Similar applications are possible in construction management, building inspection and facilities management.

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