

DYNAMIC 3D-SKETCHING

A design tool for urban and architectural design

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Abstract. Sketching by hand is without doubt – alongside building models – the most common tool that architects employ when designing. A disadvantage of the sketch is, even if it is a perspective drawing, that it is a purely two-dimensional planar representation of a three-dimensional product: the three-dimensional impression that the sketch communicates is a product of the viewer’s imagination. Digital modelling tools on the other hand support the creation of three-dimensional content but fall short in their ease of handling: their complexity and potentially un-intuitive operation hinder rather than support the design process. Taking this discrepancy as a starting point, the presented system details the development and prototypical implementation of a dynamic 3D-sketching tool. The underlying core idea is to create a seamless connection between a perspective hand-sketch and the corresponding digital 3D-model in order to benefit from the advantages of hand sketching as a design tool and computer maintained 3D models. The system allows the designer to work as usual, visualizing his or her thoughts using perspective sketches. The user sketches on a touchscreen surface. The 2D drawing is automatically interpreted and converted into a system of 3D lines, surfaces and volumes in real-time.

Keywords. Design Tool; Early Design Stages; 3D Sketching; Urban Design; HCI.

1. Introduction

The question as to how to most effectively and sensibly make use of computers to support the designer during the early design stages is a central aspect of interdisciplinary teaching and research work at the TUM. The core concept of the system described in this paper is the creation of a seamless connection between a perspective hand-sketch and a digital 3D model. This combination makes it possible to employ the benefits of hand sketching as a design tool in three-dimensional space as well as to use digital 3D models as a data basis for other calculations, analyses and optimisation procedures.

2. Design Tools

The basis of any study of design tools is an analysis of the design process. In general, the design process can be described as an idea-finding process for resolving ill-defined problems. The definition of the problem is itself part of the solution process, which means it is not possible to operationalize it in predefined steps. Design is better described as an iterative process of finding a solution to an objective that is not known in advance. An essential part of this is the process of reflection while undertaking actions, what Arnheim calls "visual thinking" (Schön, 1983; Arnheim, 1971). The direct interaction of gesture and perception leads to a never-ending cycle of gesture, perception and response. It is through the gesture and its articulation that thoughts arise and people start to think. Vilém Flusser argues that "there is no thinking that would not be articulated by a gesture (Flusser, 1991). Gestures can be expressed in a myriad of different ways, for example in writing, as a graphical image or a model – typically any medium that enables one to express a vague notion or an incomplete, sketch-life image of something.

This interplay between gesture and perception as a central aspect of this process can therefore be accorded an essential role in the idea-finding process, although it requires the use of a tool to output these thoughts. Design tools therefore directly assist the designer in his or her creative work and to a certain degree make them possible in the first place. If one considers both the properties of established design tools as well as the aforementioned conditions under which they are used, we can determine the following essential requirements that thinking tools should have:

- Simplicity of use
- Flexible application
- Direct cognitive feedback from gesture to brain
- Ability to accommodate vague input
- Step-by-step approach to problem solving

2.1. THE SKETCH

Given the above requirements, it is not hard to understand why the hand-drawn sketch is such a valuable tool in the context of architectural design. Fish and Scrivener have described the essential qualities of hand sketches as follows (Fish and Scrivener, 1990):

- Sketches contain selective and fragmentary information
- Sketches contain deliberate or accidental indeterminacies that are important to their function
- Hand-drawn sketches are 2D representations of 3D content

The first of the above qualities is of particular relevance for the usefulness of sketching as a design tool. The ability to approximately express vague and incomplete information makes it an ideal tool for gradually exploring an as yet ill-formulated idea and facilitates the process of emergence. In addition, such vague and marginal information helps the designer pick up his or her train of thought at a later date.

The third point contrasts markedly with this. The simplified representation of three-dimensional information in two-dimensional form is an essential quality of the process of visual thinking in the designer's working processes. Through this conversion into two dimensions, the complexity of an idea is reduced to its essential elements, making it more comprehensible and perceptible for the thinking process. Gänshirt, however, reminds us that this reduction also abstracts a principal aspect of what architecture and space is: "laymen cannot usually imagine three-dimensional effects and connections on the basis of two-dimensional diagrams" (Gänshirt, 2007).

2.2. DIGITAL 3D MODELS

3D modelling programs are often the very opposite of 2D sketching. They allow the detailed modelling of digital objects in three dimensions and are mostly used in the later planning phases and not in the early design stages.

A problem in this respect is the complex human machine interface of 3D systems. While mouse and keyboard make it possible to input exact, pixel-precise data, their low level of embodiment and unintuitive operation make them difficult to use in the early creative design phase. In particular, the interaction methods for creating and editing digital objects that these input methods condition mean that the working process is defined primarily by how to operate the tool: this and the need to think ahead makes it hard to think and work freely and creatively. Although there are few sensible uses for these tools in the early design phases, three-dimensional digital data is

nevertheless an essential prerequisite for conducting analyses, for visualising a design as well as for the subsequent planning process.

3. Related Work

Of particular relevance to our project is related work on 3D sketching tools. One of the first examples of such tools is Teddy, which is described as "a sketching interface for quickly and easily designing freeform models such as stuffed animals and other rotund objects" (Igarashi et al., 1999). Igarashi's focus is on the simple modelling of rounded, three-dimensional forms using a stylus. The imprecise movement of the stylus when hand-sketching is largely retained, giving the resulting object a sketch-like character. A similar approach can be seen in the "ILoveSketch" project (Bae et al.). Like Teddy, the program makes it possible to sketch three-dimensional forms. Functionality such as symmetry, however, requires the designer to think ahead and consider the constructional process so that in some cases, the drawing process can obscure the idea-finding process. But both tools do allow one to create simple freeform "3D curve models" using a pen or stylus and to interact with these. They are, however, less applicable to an architectural context due to their exclusive use of freeform bodies. An example of a 3D sketching tool in an architectonic context is Digital Clay (Schweikardt and Gross, 1998). Here, the focus lies not on creating freeforms but on reconstructing rectangular geometries. Teddy and ILoveSketch are interactive sketching tools; Digital Clay on the other hand converts the sketch into a 3D model in a second step. In this separate step, the sketched line is converted into a 3D model, and the line is also straightened. As a consequence the hand sketch and the 3D model are no longer directly congruent. A disadvantage of this approach is that it requires a finished sketch: as such it does not offer the same potential for real-time reflection and amendment as pen and paper for example, and is thus of limited use for the design-thinking process.

4. The Sketch Tool

An analysis of the design process and the associated tools quickly reveals that the solution is not to replace established tools with digital tools and computers. Instead, both worlds need to be combined in such a way as to leverage the advantages of each. Our earlier research work has followed this same principle: we created a design environment for urban planning at a scale of 1:500. By directly coupling real, volumetric models (a working model as traditionally used for urban design projects) with interactive digital content, the gap between the real models and interactive content is bridged, augmenting the otherwise purely physical model with additional information

(Schubert et al., 2011a, 2011b). The system presented here bridges another gap: it makes 3D reconstructions of 2D perspective drawings. The central question was how to convert the spatial information contained within a 2D perspective drawing on the fly into three-dimensional content so that it can be used for the design process. The project aims to use 2D perspective hand-drawn sketches as a basis for directly re-constructing 3D objects in real time during the actual process of sketching. The simultaneous availability of the 2D sketch design and proper three-dimensional digital objects in the early design stages offers significant benefits for the design and decision-making process. Calculations, analyses and simulations can be conducted in real time based on the information drawn and available parameters to provide the architect with additional feedback and information about his or her sketched idea – not, as is currently the case, after a design has been developed but directly during the process of creative design.

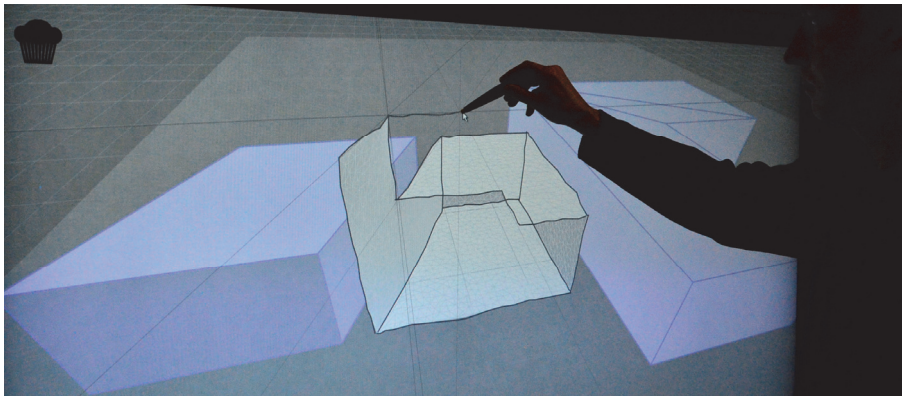


Figure 1. The 3D sketching tool makes it possible to interactively sketch on a touchscreen in three dimensions, converting the perspective drawing into digital 3D objects in real time.

Taking into account the aforementioned conditions in which design tools are used, we drew up a series of requirements for the tool:

- Ability to convert sketches and reconstruct them into 3D objects in real time, even when sketches are unfinished
- Tolerance of imprecision, vagueness and incompleteness
- Ability to relate sketching to the surrounding environment

The system presented here fulfils these requirements, making it possible to draw on a touch screen with stylus recognition, essentially enabling designers to work as usual using a tool they are familiar with. The additional availability of the idea in the form of three-dimensional digital objects also makes it possible to harness the benefits of the computer.

4.1. REAL-TIME RECONSTRUCTION

The process of visual thinking is reflexive and requires that the designer's tool of choice provides some form of real-time feedback. It is this feedback that facilitates the creative loop between designer and sketch and sketch and designer. For this, it is therefore essential that a system can reconstruct two-dimensional, perspective sketches in three-dimensional lines, surfaces and volumes in real time, even when an object has not yet been fully drawn. In addition to facilitating the process of visual thinking, it also makes it possible to change perspective and zoom in or out of the drawing, thus enabling a new kind of perspective drawing.

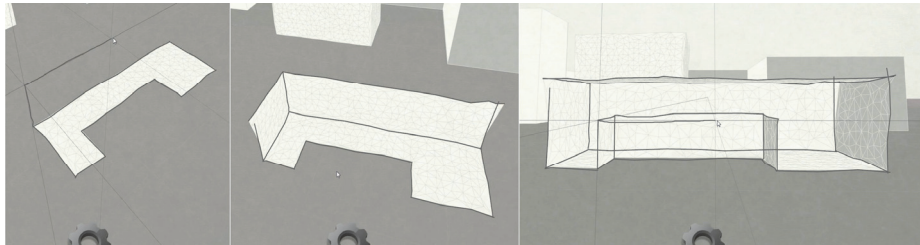


Figure 2. The real-time conversion process makes it possible to change one's point of view while sketching, opening up new ways of interacting with one's idea and stimulating new ideas through the change in perspective.

A particular aspect is the ability to reconstruct drawings that are incomplete. This makes it possible to change one's perspective while sketching, giving the architect much greater flexibility and at the same time creating good conditions for the emergence and finding of ideas. The tool can be used to look at an idea from another side and to refine it accordingly. The potential this offers is significant: the ability to change one's point of view to gain a new perspective on the problem extends what is possible with conventional pen and paper and opens up new ways of interacting with one's ideas.

4.2. IMPRECISION AND VAGUENESS

The ability to input information that may be imprecise, vague or incomplete is an essential characteristic of such design tools and can therefore be seen as a key criterion in the development of a sketch-based digital design platform. That means that new tools must not only permit the entry of vague and imprecise information but also retain this approximate nature in the corresponding reconstruction in three dimensions.

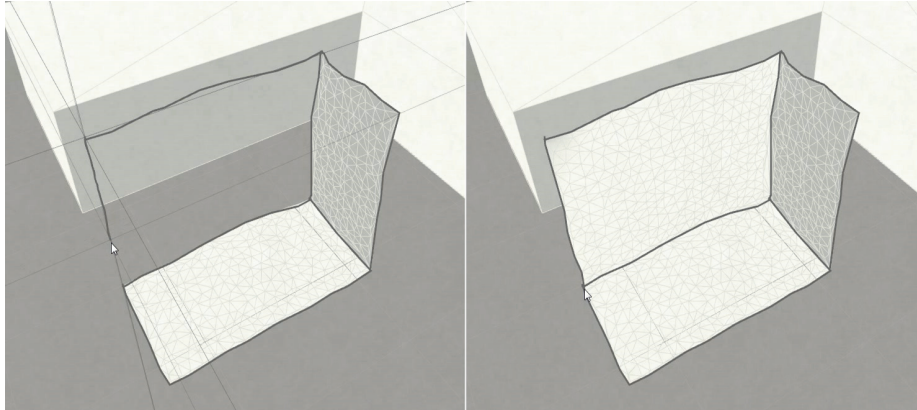


Figure 3. The ability to use a stylus or pen as an input device makes it possible to sketch imprecise and vague information. Surfaces adapt automatically to the contour lines and triangulation ensures that these maintain the imprecision of the sketch.

Lines and surfaces are not straightened, lines that cross over are not trimmed and so on, so that the reconstructed three-dimensional form resembles, as far as possible, the sketch it is based on. While this is not a problem for the representation of drawn lines, the reconstruction of the 3D structures that arise between these imprecisely drawn lines is much more difficult. To tackle this problem, the tools construct triangulated freeform surfaces between the nodes of the drawn forms. The reconstructed surfaces therefore align to a large degree with the boundary lines without becoming a precise form and the digital reconstruction accordingly reflects the approximate, imprecise nature of the drawing.

4.3. VANISHING POINTS (RELATIONSHIP TO SURROUNDINGS)

Architectural plans are not made in a vacuum: buildings must almost always be integrated into their surroundings. Typical approaches involve the adoption of and alignment – or intentional misalignment – with existing edges often using vanishing points and corresponding vanishing lines. Perspective drawings are often used to visualize situations during the early conceptual architectural design phases. Parallelism and other angular relationships commonly occur in perspective drawings and can be derived with the help of vanishing points and vanishing lines.

As a consequence, a fundamental element of the proposed system and its user interface is the use of vanishing points and lines. To assign depth to sketched strokes, the system generally needs to know where the vanishing points lie. While a common vanishing point exists for many sketches, we aimed to develop a sketching tool that is not limited just to regular cases but

also permits one to sketch irregular, imaginative and potentially physically complex to handle structures. To achieve this, our approach provides an operational set of vanishing points according to the assumed expectance of the user, without forcing him to specify vanishing points by hand. Vanishing lines are dynamically visualized when the pen touches the surface of the screen in the form of thin auxiliary guides through the starting point of a stroke and the 2D projections of the vanishing points.

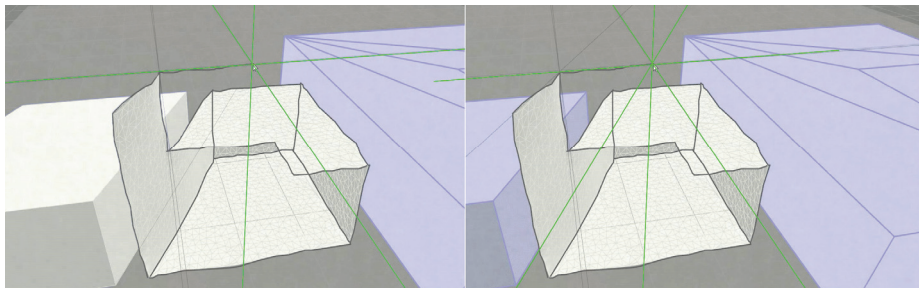


Figure 4. Vanishing points are derived automatically from the marked buildings. This increases the density of information and data available for the reconstruction of the drawings.

This way, the user can follow one of the vanishing lines or can choose to deliberately deviate from them when sketching a different orientation. The system provides the main coordinate axes by default and adds a small operative set of vanishing points through which the guides are drawn to avoid cluttering the screen. These lines appear whenever the user taps an existing building in the vicinity and disappear when the user taps the surface again.

5. Implementation

The implementation consistently maintains the user's strokes as drawn, but is internally based on an iterative analysis and a graph-based structure. The graph structure is built in consecutive steps. First, the user's hand-drawn strokes are segmented into straight lines. Second, the strokes are mapped to vanishing lines, if applicable. The third step maps strokes to junctions, which is necessary to allow the user to change perspective. From these junctions, faces are detected and the 3D geometry is generated. The following describes the individual steps in more detail:

- Stroke segmentation: we used a segmentation procedure based on the Ramer-Douglas-Peucker (RDP) algorithm (Douglas, 1973), which searches the set of pixels along the curve for the pixel with the largest distance from the approximated multi-line (starting with the two endpoints as a rough approximation). If the distance is larger than a threshold value, the algorithm splits the line at

the target pixel and repeats the procedure recursively for the resulting segments. We performed simplification in two steps, applying the RDP algorithm twice, but with different threshold values. The thresholds we used are 1.5 and 20 pixels for each step respectively. The first step serves simply to downsample the stroke complexity and has a negligible impact on the stroke quality. The second step executes the actual segmentation. False negatives occur very rarely due to the low thresholds used for the RDP algorithm as well as the use of guides, which reduce error substantially.

- Mapping strokes to vanishing points: to assign a stroke to a certain vanishing point, it is compared with each vanishing line in the given operational set of vanishing points. A stroke is mapped to a vanishing line when it deviates on average by less than 25 pixels (1.9 cm on the 65 inch screen) from the line, with no individual pixel diverging further than 50px from the vanishing line.
- Mapping strokes to junctions: the detection of junctions uses proximity to join strokes. Prior testing among several users with different levels of expertise yielded a threshold value of 15 pixels for sketch corner end points to junctions. The process produces an undirected graph with junctions represented as nodes and stroke edges as edges. This graph is extended by the assigned vanishing points to weight the connecting edges.
- Sketch reconstruction: to finally reconstruct the 3D shape, one needs to ascertain the scale factor of the sketch and the faces must be detected and filled to yield a more readily perceivable representation. To establish the exact scale of the 3D object, a single relationship between a 2D entity on the projection plane and its corresponding 3D entity in world space needs to be known. As observed in an early investigative study on architectural sketching work, the first face that is sketched usually defines the building outline flat on the ground. We therefore compute the first 3D points by projecting this first sketched face onto the ground. The correspondence between the 3D position of the projected face and its 2D projection on the sketching plane yields the scaling factor and provides us with a starting point for the final reconstruction. Faces are detected by finding cycles in the graph. Once a new face is detected, the points along the edges of the face are collected and a triangulation is computed to fill the surface with a mesh.

These steps are executed on each new stroke as it is added to the sketch, making it possible to respond dynamically to changes and enabling the user to change viewpoint and perspective mid sketch. The user does not have to use any system control mechanism. Only the pen and the space mouse are used to change viewpoint allowing the designer to focus fully on the design.

6. Conclusion

In this paper we describe the prototypical development of an interactive 3D sketching tool. Because there is no unequivocal way to interpret a 2D perspective, it is not entirely possible to recreate the experience of freehand sketching with pen and paper while simultaneously creating 3D objects. We have, however, been able to provide a high degree of creative freedom while requiring only two boundary parameters: a vanishing point as orientation and definition of the footprint. The resulting system shows the potential that lies in the automatic interpretation of 2D perspectives as 3D volumetric drawings. Without relinquishing the ability to use established thinking tools or hindering the design process with additional modelling steps or a complex UI, the designer's ideas are presented in multiple dimensions: the information within the sketch is extended into an additional dimension. This gives the designer new possibilities during the thinking process, such as the ability to change perspective while sketching. In addition, it is possible to provide relevant information to support design decision. In future research we aim to extend its application by facilitating the recognition of freeform bodies. An evaluation of the tool in everyday practice is currently underway.

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