

# **3D Virtuality Sketching: Interactive 3D-sketching based on real models in a virtual scene**

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## **Abstract**

Sketches and working models are without doubt one of the most widely used tools in the architect's repertoire. In the early phases of the design process in particular, they represent an essential part of the exploration process. For the most part, however, sketching and model building are separate and sequential steps. This paper examines how both media can be linked to each other more effectively so that the design process is more continuous and the transition between the two media more fluid. Using a multi-touch table with additional 3D real-time object recognition, a prototypical system was developed and realised as part of a research project in which an interactive 3D sketching tool was linked with a real 3D working model.

## **1 Introduction**

In an interdisciplinary project we examined new approaches for using computers and information technology in the early creative phases of the design process. The aim is to develop digital tools that strengthen rather than hinder the design process so that a continuous workflow results according to the motto "the simpler the tool is to use, the less it gets in the way of the actual process of designing". As a result, established design tools are not entirely replaced by digital methods but instead combined with a view to making the most of both worlds: by combining the advantages of each realm, we expand the possibilities of designing in real and virtual environments.

Building on the pre-existing "Collaborative Design Platform" (CDP) (Schubert et al. 2011a, 2011b), we examined aspects of human-computer interaction and the use of computers in the early design phases.

The sub-project described in this paper is a 3D sketching tool for the early architectural design phases that makes it possible to annotate, extend and label real working models in a virtual environment in real time. We examine how linking together established design tools – the sketch and working model – can contribute to supporting a continuous design process and what advantages this may have for the designer.

## **2 Design tools**

Imagining future situations has been a fundamental part of the work of an architect since the end of the Renaissance. As building projects became ever larger and more complex it

became necessary to find methods for envisioning the building process and to verify the design and construction in advance: “The whole point of having the process of design separated from the process of making is that proposals for new artefacts can be checked before they are put into production” (Cross 2008; Buxton 2007). Or as Fish and Scrivener describe it: “The use of words, pictures or models to stand for objects, scenes or events not physically present enormously increases the mind’s ability to visualise” (Fish and Scrivener 1990).

Over the years as culture progressed, different tools have been used to support the design process. Surprisingly, despite the widespread use of computers in architectural practice, computers have not become an established tool in the early design phases. Working models and freehand sketches on the other hand remain fundamental design tools at the beginning of the design process. Depending on the design brief and the specific design problem, architects use one or the other as a tool to assist thinking. Numerous academic papers and books have examined the topic of design tools, creativity and finding ideas, as well as what characterises design problems and processes. The findings can be broadly summarised as follows: design tools are used to represent and to test one’s own ideas. They help the designer to create an externalised image of their thoughts – that is, they render the designer’s thoughts visible and accordingly support the creative process of designing. The architect “holds a conversation with the drawing,” as Schön describes it (Schön 1983). The process of drawing helps engage in what Schön calls “the reflection in action process”: first, the architect frames the problem in order to come up with an idea. He tries to understand and to define the problem. Secondly, he draws the idea. While drawing the idea the architect simultaneously reflects on the idea, evaluating its consequences and implications, a process that can lead to a new or refined idea. The process then repeats. This process, which has been termed also “visual thinking”, is a key characteristic of the architectural design process (Arnheim 1971).

In response to the above, the freehand sketch and working model have become standard tools. If one takes a closer look at each of these tools one can note the following characteristics:

**Table 1: Comparison of freehand sketch and model**

<b>Freehand sketch</b>	<b>Working model</b>
2D	3D
Quick and flexible	Better spatial impression
Can represent any scale	Can be explored and revised with both hands
	Tactile feedback

The differences noted here are actually qualities that speak for one or the other tool, and if one looks closely it is apparent that they hardly relate to one another. Although both tools are used in the design process, they are rarely used in combination. As a result, switching between the different media interrupts the design process and creative workflow. The research project takes this as its starting point and examines the possibilities offered by linking the sketch to the working model with the help of computer technology. The aim of this project is to connect existing and established design tools

with a view to optimising the use and advantages of both.

### **3. The sketch**

Freehand sketching is a design method that has been widely used for hundreds of years, and more so than perhaps any other method. Its popularity is, of course, not a coincidence but rather a factor of its special qualities. Fish and Scrivener list four important attributes of sketches (Fish and Scrivener 1990). Of particular interest in this respect is the ability to depict abstractions at different levels (Cross 2008), to embody indeterminacy (Buxton 2007) and with it to allow ideas to emerge are among the most fundamental attributes of a freehand sketch. But why is this?

In the early design phases, the information available is often vague and incomplete. The ideas that float around in the designer's mind are not yet well formed. A design tool needs to be able to accommodate these kinds of imprecise thoughts and vague information. This is essential for a dialogue between the designer and the drawing to arise, which in turn serves as a basis for refining and developing the idea.

Closely related to this is the concept of emergence. The term emergence describes the process of making qualities and things visible that cannot be explicitly formulated or depicted (Gero, Damski and Han 1995). In the context of designing, this is essential as it helps the designer to perceive something in a drawing that may not be what he originally drew. The sketch as a design tool and its capacity to accommodate emergence represents a catalyst for stimulating not yet conceived interpretations of an idea put down on paper (Buxton 2007). This applies particularly when drawing on top of existing images, renderings and sketches. In contrast to a sketch drawn on an empty piece of paper without any reference image, drawing over existing sketches stimulates the process of emergence – and therefore visual thinking – much more strongly. The combination of image and sketch, in particular, can bring forth entirely new forms resulting in the emergence of new ideas and inspiration.

### **4. User scenario: an urban design competition**

An architect is tasked with developing a design for an urban environment. Rather than working on screen with a mouse and keyboard, he or she uses a large multi-touch table equipped with real-time object recognition that will 'see' the objects in the model. To begin with, a site plan of the competition site and surroundings can be seen on the table.

The architect begins by cutting blocks to size out of a material of his or her choice for use with the model so that the positioning of approximate building volumes can be tested. After some experimentation, he settles on a first potential constellation. The next step is to examine how the vertical articulation of the blocks and façade design will influence the design. He places a "spacemouse" with a camera symbol on the multi-touch table and an "ego perspective" of his design idea appears on a touch screen arranged next to the model (3Dconnexion: SpaceMouse Pro). He positions the mouse on the multi-touch table in such a way that his design idea is shown fully in the perspective view on screen and then picks up a pen and starts to draw his ideas for the façade design on the perspective view on the screen. In the background, the system maps his sketches in real-time onto the surfaces of the 3D volumes.

After a while, he asks a colleague for input on the design as it stands. His colleague has a few ideas and shifts some of the blocks in the real 3D model on the multi-touch table. The perspective view on the screen updates accordingly to correspond to the new arrangement of the real model. Because the façade designs have been intelligently mapped to the building surfaces in the virtual model, they shift along with the blocks.

To show his idea more clearly, the colleague shifts and tilts the Spacemouse to adjust the perspective view. Turning to the touch screen, he picks up the pen and annotates the changes to the urban situation in the perspective view on screen with comments, arrows, text and hatching. The two colleagues continue to refine and improve their idea, discussing alternate means façade articulation and urban constellations.

## **5. Related work**

Research into the use of sketching tools for the early design stages is not a new area of research. Some simple to use, geometry-based approaches to making virtual modelling tools include Sculptor and DDDoolz (Kurmann 1995; Achten, de Vries and Jessurun 2000). By replicating established ways of working, e.g. from model building, these tools make it simple to create simple three-dimensional volumes in digital space. Further approaches can also be found in the realm of VR and AR, for example “3DM”, a very early approach for modelling 3D-environments (Butterworth et al. 1992). By using a Head-Mounted-Display and sketching while being immersed inside a virtual environment it combines techniques from CAD as well as drawing programs. A contrasting approach can be seen in “the augmented round table” which provides an interactive AR-environment where users can create and manipulate virtual 3D-objects in a real environment (Wolfgang Broll 2003). However, the adaptation of real processes into a digital environment removes the direct relationship to what is being designed and likewise any haptic feedback. The result is unintuitive and not well suited for reflexive creative processes. Approaches such as that used by Sculptor, which implements an additional physics engine so that the objects in the scene act as naturally as possible can help compensate for this deficit. The idea of the CDP is a response to the problem of porting analogue ways of working to the computer. Rather than replacing these analogue design tools, it links them with the computer so that they retain their elementary qualities but are also extended through additional digital support.

Another approach can be seen in the use of sketch-based tools. The first tool to use pen input is Sketchpad by Ivan Sutherland (Sutherland 1963). Sketchpad made it possible to “directly” manipulate graphical objects on screen using a light pen. Johnson took this concept further and developed Sketchpad III, a tool for creating three-dimensional volumes using a stylus (Johnson 1963). In the field of 2½D sketching a design tool called “sketch book” was developed and tested in 2009 which makes it possible to hand sketch in a virtual 3D scene. For this analogue to the real world a transparency layer – much like real sketching paper – is laid over the entire virtual scene (Schneider and Petzold 2009). In a commercial environment, a similar texturing tool is “Bodypaint 3D” by Maxon (MAXON: Why this package?). Using a UV mesh, the software can apply textures directly to a 3D volume or the object’s net shape. These solutions require one to construct a virtual 3D model first. Due to the complex interfaces of current 3D CAD software the creation of a virtual model is complex and time consuming. This intermediate stage

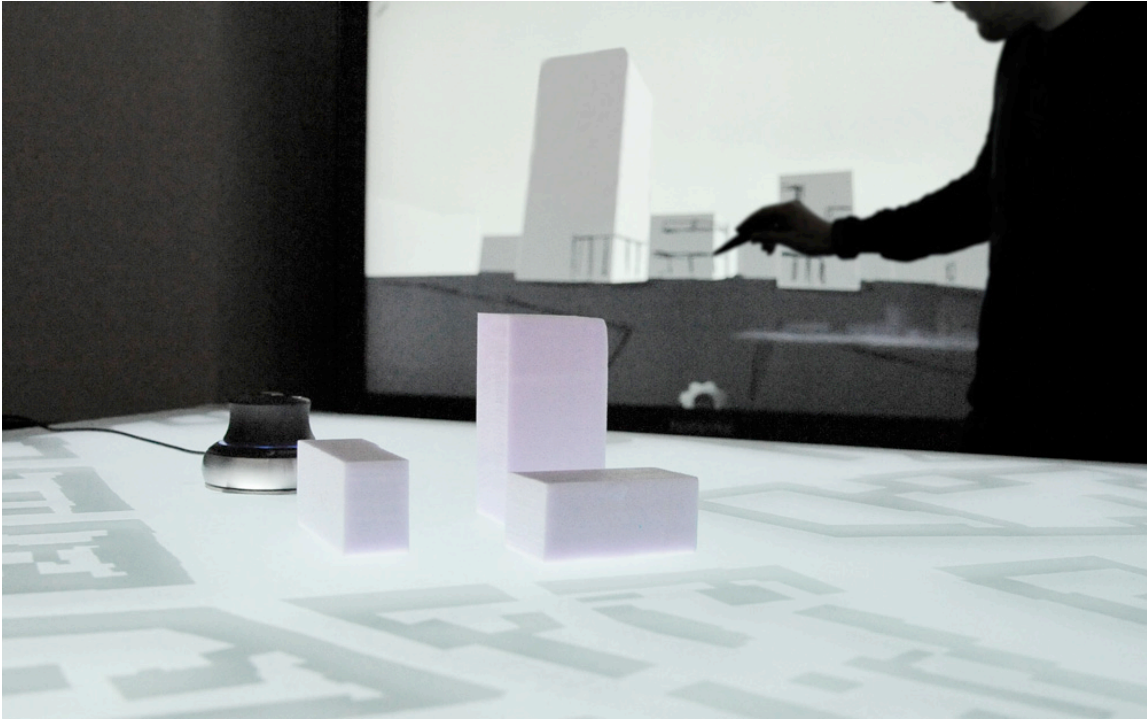
represents an undesirable interruption in the design process. Two well-known examples of 3D sketching tools are Teddy and Digital Clay (Igarashi, Matsuoka and Tanaka 1999; Schweikardt and Gross 1998). Both facilitate the generation of 3D freeform shapes from freehand sketches. In addition Teddy supports drawing and sketching in three dimensions directly onto the generated surfaces, including colouring them in.

Although these tools offer an intuitive means of operation using a pen-stylus, the fact that they handle just one field of activity means that one has to change tools for different tasks, interrupting the process. By directly linking the physical working model with the interactive scene and by combining different drawing methods, our project provides a near-seamless fusion of two well-established design tools but without replacing them. The core properties of the tools – rapid and intuitive handling, fuzzy precision, haptic quality and a direct connection to what is being designed – are maintained. By coupling the two directly, they can work hand in hand, making it possible to work at multiple levels. The interactive platform opens up new ways of designing in the architectural design process.

## **6. The sketch tool**

The project shown here builds on work done last on year on a developed design environment for urban planning at a scale of 1:500. By directly coupling a real, volumetric model (a working model as traditionally used for urban design projects) with interactive digital content, the gap between the real model and interactive content is bridged, expanding the information that is stored with the otherwise purely physical model (Schubert et al. 2011a, 2011b). The technical basis for the design platform is a large-format multi-touch table. Coupled with real-time 3D object recognition, the table acts as a ‘tangible interface’ that, in addition to reacting to touches and markers, can sense objects on the table. The three-dimensional data from the model on the multi-touch table can serve as the basis for simulations, analyses and rough calculations. The designer is provided with an additional information layer containing simulation data and analyses that are displayed directly on the model and help him evaluate the consequences of design decisions. The physical model and the computer, previously two separate realms, are now united resulting in a continuous design process without interruptions when switching between media.

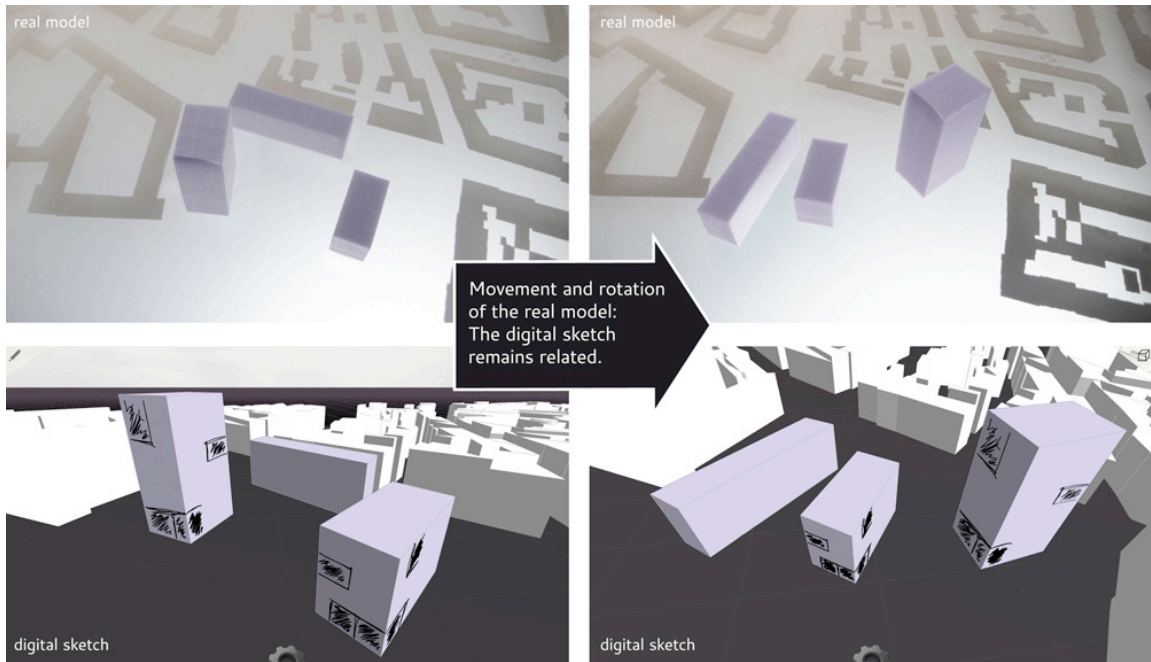
This basis has been extended in this sub-project to include an interactive drawing tool. In this situation, the multi-touch table functions as the input device for the real, volumetric model. A separate touch screen is set up parallel to this. The scene on the table (consisting of GIS data structure, the 3D data of the scanned real model as well as supplementary simulation data) is displayed as a real-time perspective view on the touch screen. The direct and synchronous connection between the model environment and the touch screen makes it possible to interactively connect both tools. The designer works with the working model on the table. Further options can be added in real time on the additional touch screen using a pen applied to a perspective view of the design scenario. The user can draw on and in the design scenario, annotating and interacting.



**Figure 1. System setup: multi-touch table with integrated 3D object recognition and directly linked 3D-drawing tool in the background**

In contrast to an analogue sketch on paper, this system allows one to draw directly in the 3D scene. The architect can, for example, draw the façade directly onto the surface of the model.

Due to the digital basis and parity with the real volumetric model, the digital sketch and the real model can be thought of as a single entity. This direct coupling makes it possible to work in a familiar way (move, rotate, cut) with a real model in three dimensions. At the same time, any digital notes or sketches remain related directly to the respective real object.

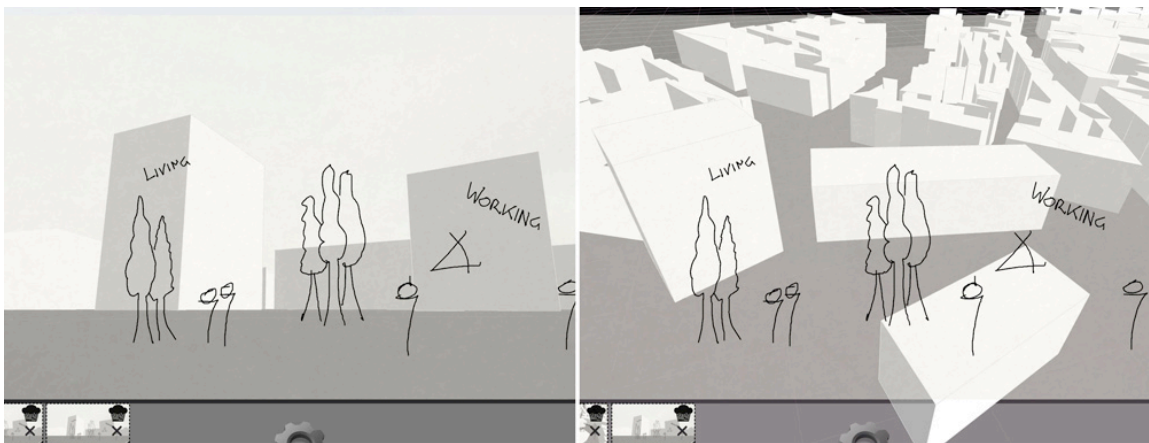


**Figure 2. Working model and sketch directly coupled with one another.**

This three-dimensional link-up between model and digital content means that the user can draw in the digital scene using different modes: paper, object, extended and 3D sketch.

### 6.1 Paper Mode | 2D

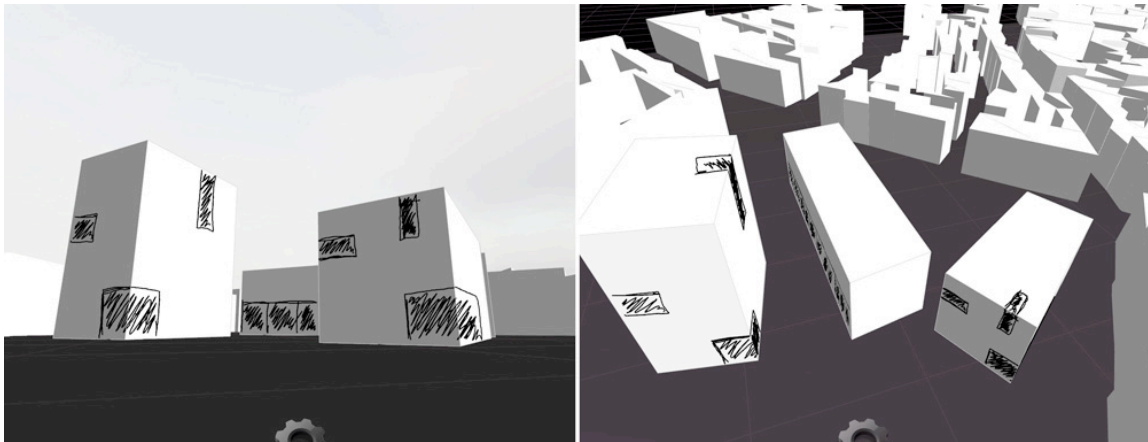
This function is in a manner similar to tracing paper: a semi-transparent layer is laid across the entire scene onto which one can draw and sketch without having to adhere to any particular geometry. As such this mode is very similar to the traditional method of using tracing paper with a drawing beneath it. The sketch and the relationship to the 3D scene is dependent on the viewing position and is always parallel to the front face of the camera. A mapping function can be used to “bake” the drawing onto the texture of the 3D volumes.



**Figure 3. 2D Paper Mode: sketching on a semi-transparent layer (left image). No relationship between real model and sketch (right image). Drawings can be mapped onto the objects, and therefore linked to them, using a “bake” function.**

### 6.2 Object Mode | 2½ D:

In Object Mode, individual objects, buildings and surfaces are recognised, independent of whether they derive from the real working model or from the underlying GIS data of the surrounding buildings. This makes it possible to draw directly onto individual objects and buildings in the modal. For this, the drawing is computed into a vectoral texture, referenced in three-dimensional space, and displayed on the respective surface in the scene. In other words, the sketch is mapped to the envelope of a building and makes it possible to draw in perspective onto the scene shown on the screen. The relationship to the object is maintained, which means that the mapping remains in place when the building volume or the camera position changes.



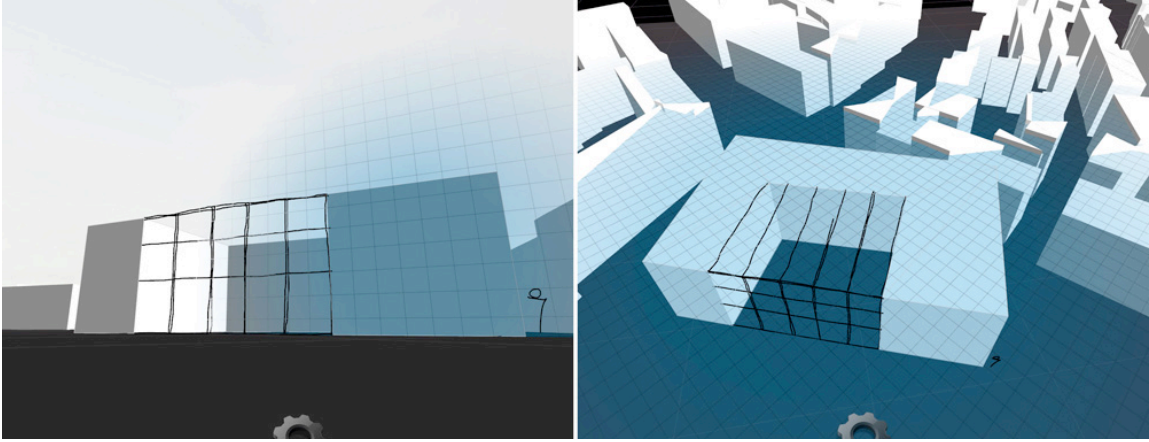
**Figure 4. Object Mode: 2½D sketching on the surface of objects (left image). Direct connection between sketch and real model: the sketch remains connected to the model even when the real model is moved or turned (right image).**

### 6.3 Extended Mode | 2½ D

As with Object Mode, the surfaces in the model are automatically recognised and the sketch is directly mapped to the object’s surface. What differs in this mode is that by clicking on the current surface, a new infinitely-wide three-dimensional plane is created, based on the clicked-on layer, that spans across the entire scene.

This makes it possible for the user to draw semi-freely in three-dimensional space, to extend building geometries or connect buildings to one another.

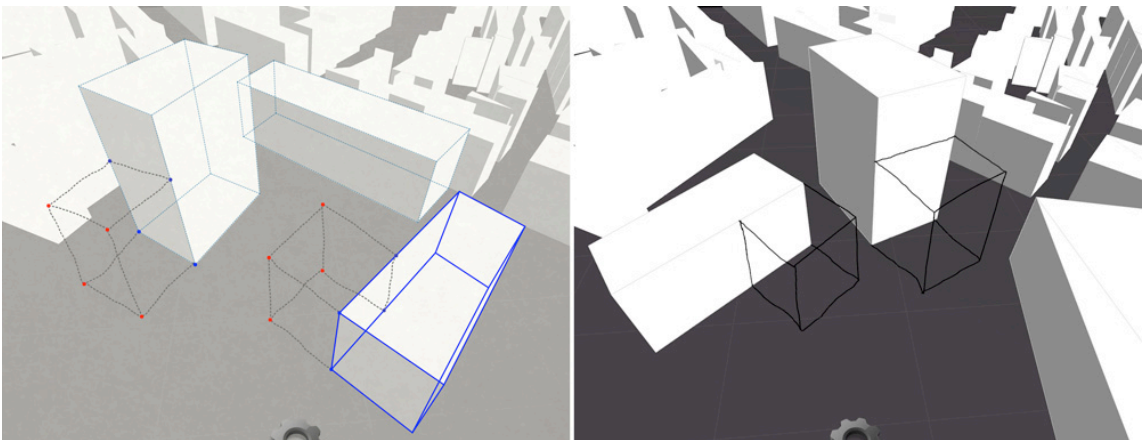




**Figure 5. Extended Mode: 2½D sketching on a freestanding surface in space. Supporting layers can be created simply by clicking on a surface. The sketch is linked to the selected real object and changes its position with respect to the position of the real model when it is moved or turned.**

#### 6.4 3D Sketch | 3D:

In addition to the purely 2D and 2½D modes, a 3D mode has also been implemented. Using the existing 3D data as its reference and environment, this drawing mode makes it possible to create three-dimensional mesh models. Three-dimensional structures can be drawn in two dimensions and then automatically converted into three-dimensional objects that sit within the existing 3D structure of the model.



**Figure 6. 3D Sketch Mode: freehand 3D sketching linked directly to the real object.**

### 7. User Interfaces (UI) for creative processes

Based on the findings of several researchers working on creativity research in human-computer interaction, we describe how user interfaces can enhance creative processes (Shneiderman 2000; Resnick 2005; Terry 2002). Resnick et al. have found design principles for tools to support creative thinking. Terry and Mynatt also recognize creative

needs in user interface design and provide guidelines for UIs used in creative work. Their main focus is on the creation and evaluation of an idea. Based on their findings we identified important requirements for the user interface in our architectural context:

### 7.1 Provide the ability to sketch

Hand drawn sketches and diagrams are essential tools for architects' creative reflection (Resnick et al. 2005) and we therefore provide a sketching tool. As we have seen in section 3, the visual appearance of a sketch plays a central role in the ideation phase, and the creativity tool should not change its nature. The original sketch is preserved along with all its inaccuracies, irregularities and wobbly lines that may serve as a spark of illumination in the ideation stage, when a new idea arises.

The sketchy, unpolished appearance has a further advantage in that it doesn't give the impression of being complete. There is no illusion that a lot of effort has been given to carefully elaborating the idea. Purcell and Gero call this phase design fixation (Purcell and Gero 1998). The presentation of an idea in a form that is too polished hinders the creation of new ideas and fosters premature fixation on a certain idea.

### 7.2 Cycles of ideation and evaluation – exploration of alternatives

The generation of a large amount of ideas that are constantly being evaluated is a characteristic of the creative process cited by many researchers (Shneiderman 2000; Resnick et al. 2005; Robertson and Radcliffe 2009; Terry and Mynatt 2002). Terry and Mynatt examine the exploration of alternatives and their evaluation in detail (Terry and Mynatt 2002) and note that "interfaces should offer a dedicated space in which to perform near-term experiments, without needing to modify the document or its data. This capability is sometimes called a 'what-if' tool."

Many user interfaces, however, force the user to progress linearly through a task where each step replaces the current state with a new state (Terry and Mynatt 2002). In the paper mode of our 3d virtuality sketching tool (see section 6), we have avoided this additional burden to the user and do not require the user to explicitly create copies of their data to create multiple versions. In this mode it is possible to generate variations sequentially (one after the other) or in parallel (multiple ideas at the same time). A new 'sheet' of paper is simply added to the scene by dragging one out, while the previous version is shown in miniature on screen. Multiple miniature views of the same scene are visible at the same time. By clicking on one of the miniatures the user can return to an earlier variant. Variants can also be deleted at any time. Once the user is satisfied with a sketch, he or she can incorporate it by 'baking' it into the scene. The sketch becomes an integral part of the 3D scene and is always shown with further new variations.

### 7.3 The influence of the user interface on the idea

Robertson and Radcliffe describe the ways in which a CAD tool can influence the design problem when used to solve creative problems (Robertson and Radcliffe 2009). Software limitations, in particular, along with bugs, can cause significant disruption during the problem solving process.

The creative solution can also be influenced by the designer's proficiency with a given tool. Time pressure may result in generating ideas that are easy to make with a particular tool. Ideas that may be more suitable but are more difficult to make may not be investigated. Conversely, when a designer is particularly proficient with a tool, it can also result in the production of sophisticated but sometimes unnecessarily complex solutions.

Resnick et al. argue that a creative user interface should have a 'low threshold' for beginners but also a 'high ceiling' for experts to create outstanding projects (Resnick et al. 2005). In addition interfaces should offer 'wide walls' in order to be able to explore a wide range of different ideas.

In order to create a system with maximum freedom for the user, the interaction needs to be intuitive and simple. The user draws directly in 3D on the multi-touch screen as he would do with pen and paper (see section 6), a simple and intuitive means of interaction with the tool.

#### 7.4 Support, collaboration and discussion

A large part of the architectural design process is accompanied and propelled by conversation between members of the design team and between the design team and their clients, the building's users or other participants (Lawson and Loke 1997). Small group meetings with rapid sketching and discussion are particularly effective (Robertson and Radcliffe 2009). Ideas can be reviewed collaboratively and new ideas may arise as a product of the diverse backgrounds of the group's members. A CAD tool on a normal personal computer is not conducive to this process. Aside from the software limitations, people can't work collaboratively standing in a crowd around the operator.

Our setup consists of a multi-touch table and a touch screen that fosters collaborative work by enabling several participants to work at the same time on the same scenario. Currently, multiple people can work with the physical model on the multi-touch table or change the camera view, while at the same time up to two people can work on the touch screen. The number of touch screen operators could be extended if the hardware were able to detect more than two touch points simultaneously. Additionally it would be possible to collaborate remotely, because the scenario and the sketches are digitally transferable.

### 8. Conclusion

The concept shown in this paper describes an interactive sketching environment based on a real volumetric model and combines established design tools in a new and intuitive way. The direct coupling of a physical working model with an interactive 3D sketch tool opens up totally new ways of approaching architectural design problems. Taking into account ergonomic aspects and the patterns and workflow of architectural design problems, an interactive 3D sketch environment was developed and realised in prototypical form. The resulting system overcomes many of the interruptions caused by switching from model to sketch to computer visualisation, creating the conditions for a continuous design workflow. In addition, the ability to sketch over other sketches or to sketch inside other sketches provides immediate distortion-free feedback and facilitates the process of visual thinking in a completely new way.

An initial assessment of the evaluation undertaken shows how the tool presented here can be used. Most notably the intuitive ease of use – a product of their direct coupling, the continuous workflow, and the resulting integrity of idea, model and sketch – changes the way people think and work. What was particularly apparent is that real-time feedback makes it possible to make more changes, to see more things and project more, resulting in the production of a greater number of design variants. “You have the paper, you have the foam, you have CAD... but when you have all of them together, this helps you to focus on creativity.” If one observes collaboration within a group of people, one can see that the roles are more clearly distributed. People draw simultaneously in a model, or divide up the work to each of the different media, model and sketch. In future evaluations we will use a design task to compare established analogue ways of working with designing using the CDP with a view to revealing the weaknesses and benefits of the system in practical use.

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