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Interactive 3D canvases for a coarse-to-fine sketching Application to conceptual design in architecture

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Résumé

In this digital age, architects usually alternate between paper sketch and digital softwares. Therefore, our goal is to propose a method enabling coarse to fine sketching and representation of uncertainty in a tool adapted to architectural design. Our solution is based on a new concept of interactive 3D canvases. More specifically, our contributions are : 3D canvases used as bounding volume for interactive coarse to fine creation, display and interaction in "onion peel" and the possibility to manage uncertainty by a navigation through the different options sketched by the user. A user study conducted with architects highlighted the interest of such a system in conceptual architectural design.

Mots clé : JFIG 2018, Sketch-based modeling, Computer graphics, Architecture, Geometric modeling

1. Introduction

Since the advent of digital tools, architects have had to learn how to use specialized and technical software that does not encourage creativity and require extensive training. For example, the BIM (Building Information Models [Aut02]) tool has become unavoidable. It directly imposes a very specific level of detail for each element created (choice of material, dimensions ...). This is not desirable during the design phase. In comparison, the use of a paper sketch allows for a more global and natural vision of a project in progress and also enables to represent uncertainty. For this reason, architects like those of the SCAU agency who collaborated on this project, usually alternate between paper sketch and digital softwares. Moreover, no transition exists between the paper sketch and the digital tools, once the project drafted on paper, it is therefore necessary to completely re-create it from scratch on the software.

The aim of this research was to identify the precise needs of architects and to propose a progressive digital design system that meets all the requested criteria. Our solution is based on an interactive 3D canvas concept that follows a recursive approach of creation of bounding volumes on which the user can draw or perform actions. Each bounding volume or 3D canvas represents a semi-transparent layer which can be displayed or deleted at any time. The system is called "onion peel". In addition, the user can represent the uncertainty of elements and try different options to keep the indeterminacy throughout the project. This system allows suc-

cessive iterations and refinements which are the essence of the design phase in architecture.

2. Related work

In computer graphics, the problem of interactive design is associated to sketch-based modeling that consists of creating a model (2.5D or 3D) from 2D sketches. This modeling promotes user creativity by seeking to hide the complexity of underlying digital software. A state of the art of sketch modeling [CSGC16] presents the different aspects of this kind of modeling.

In particular, the methods currently applicable to architecture belong to two main categories:

- 1) inference of a 3D model from the 2D drawing.
- 2) drawing on 2D canvases placed in 3D space,

Inference of a 3D model from the 2D drawing

Incorporating prior knowledge to infer a 3D model from 2D sketches is very common in sketch-based modeling. However it is very related to a specific domain, for example using developable surfaces to model garments [JHR*15] and [FBR*17]. To our best knowledge, the method of Nishida et al. [NGDA*16] is the only one of this category related to architecture. This method combines sketch-based modeling with procedural modeling. They use Deep Learning methods to train a convolutional neurons network to determine procedural models of building (pre-existing architectural elements) closest to a user's sketch. The approach allows coarse to fine progressive creation and the elements of the building are gathered in entities. The user selects the

mode corresponding to the entity he is going to draw. The network of neurons determines the closest procedural model and replaces the sketch with the 3D model, other possible 3D models are offered to the user who can change the model to apply.

Drawing on 2D canvases placed in 3D space

The goal of this category is to enable designers to continue manipulating 2D data (look around 2D sketches, manipulating 2D strokes) instead of imposing them 3D reconstructions which can be not desired in the design phase.

Sketching Mental Canvas [DXS*07] is the forerunner of the sketching method consisting in drawing strokes on 2D planes (or canvases). Canvases can be positioned and oriented in 3D space and the user has the possibility to project strokes from one canvas to another to create a 3D structure from 2D sketches.

Cultural Heritage The systems developed by Chen et al. [CMH*10] and in *CHER-ish* [RLT*17] associate an image organization tool with a sketching environment similar to the Mental Canvas' [DXS*07] one to create a 3D representation of historical and urban sites or structures. For the image organization system, the method of Chen et al. [CMH*10] uses user's strokes to estimate the relative positioning of an image compared to another when in *CHER-ish* [RLT*17] the user can insert an image into any already created 2D canvas that can be positioned and oriented in 3D space.

Context Insitu [PKM*11] is a conceptual design system that places the user in an 3D natural or man-made environment. They have combined the representation of a complex site, created by merging several types of data (elevation map, photographs, aerial map, plan of the site) and a sketching system similar to the Mental Canvas' [DXS*07] one which allows the interaction and the conceptual design directly on the spot ("in situ").

Interpretation of Sketches SmartCanvas [ZLDM16] is an interactive system that interprets dynamically 2D sketches. The user draws on an image then the system classifies the different strokes of the drawing into coplanar groups. Adjacency relations (contact or junctions and hinges) between the different groups are established and the user may at any time accept, modify or assign adjacency relationships between drawn features. An optimization algorithm that uses these relationships helps to automatically determine the placement of a 2D canvas in 3D space so that these different strokes are represented in the environment.

Evaluation of these systems with regard to architecture needs will be provided in Section 3.1

3. Methodology

3.1. Pre-user study

After a week of observations at the architecture agency SCAU, we submitted a survey to a dozen architects of this agency on the constraints to be included in the new tool to propose. We extracted 6 criteria from their requests :

- A coarse-to-fine approach

- Keeping the free-handed drawing
- Allowing an immediate immersion into the system
- Enabling the representation of the uncertainty and the navigation between different options
- Including 3D navigation allowing to keep on drawing from another view point
- Accepting the import of external sources (pictures, sketches, background..)

After comparing these needs to both digital architecture softwares, Revit [Aut02] from Autodesk and Google SketchUp [Tri00] (generally used at earlier stages), and sketch-based modeling methods in computer graphics, we were able to highlight that no tool met all these criteria (see Figure 1).

3.2. Overview

The main goal of our method is to propose a digital system matching all the criteria above, in particular a progressive design, from a rough sketch to the details. According to the criteria to be respected, the type of modeling system chosen must enable the uncertainty and the navigation between different options and allow a progressive drawing with a coarse-to-fine approach. The type of sketch chosen is vectorial.

The proposed solution is based on a new concept of 3D interactive canvas with the following contributions:

- 1) Recursive creation of nested bounding volume,
- 2) Display and interaction in "onion peel",
- 3) Uncertainty representation and navigation

4. Recursive creation of nested bounding volumes

The proposed method follows a recursive approach to create bounding volumes, that is to say 3D freeform canvases, on which the user can recursively draw or perform actions. At each iteration, the user draws in a freehanded manner in the plane or on one of the bounding volumes already displayed on the screen. A new bounding volume is then created by extruding as illustrated in Figure 2, the user's stroke with respect to a given direction. Verticality is a concept specific to architecture and also important in the design phase. The user has thus the choice to build a bounding volume with respect to the vertical direction or to the direction orthogonal to the face on which he drew his stroke. Keeping the freehand drawing is not a common feature in digital tools. As a solution, we have used a ray casting approach. A ray is thrown from the camera's position and is directed such that its projection on the screen is the position of the mouse. Then all the objects that are on the way of that ray are saved as well as information about the impact of the ray. This method allows us to be the most faithful to the user's stroke by detecting point after point the correspondences between the coordinates of the mouse on the screen and the intersection of the created ray with the closest object.

5. Display and interaction in "onion peel"

Being able to refine any part of a drawing at any moment is essential in the phase of the design of a project. Indeed,

Methods/ Softwares	Coarse to fine design	Freehand drawing	Immediate handling	Uncertainty		3D Navigation	Import
				Representation	Navigation		
Mental Canvas (2007)	No	Yes	Yes	Yes	No	Yes	Yes
Chen et al (2010)	No	Yes	N/A	Yes	No	Yes	Yes
In-situ (2011)	No	Yes	Yes	Yes	No	Yes	Yes
Smart Canvas (2016)	No	Yes	No	No	No	Yes	Yes
Nishida et al. (2016)	Yes	No	Yes	No	No	No	No
CHERish (2017)	No	Yes	No	No	No	Yes	Yes
Google SketchUp	Yes	Limitations	No	No	No	Yes	Yes
BIM-Revit	No	Limitations	No	No	No	Yes	Yes

Figure 1: Summary and comparative table of the architectural methods and the architects' criteria

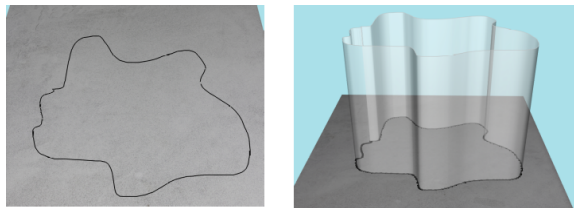


Figure 2: Creation of bounding volume by extrusion of a user's stroke along the vertical direction

a project evolves from an initial idea to the finished model by iterative refinements. Each bounding volume represents a semi-transparent layer which can be deleted or displayed at any time allowing the designer to nested forms as it is often the case in architecture. Removing layers allows a design inside a bounding volume or on a volume which would be behind others volumes. The system is called "onion peel". In addition, the user can cut any bounding volume by a cutting line drawn in a freehanded manner as illustrated in Figure 3. To realize the cut of a volume, a local reference is determined around the cutting line. A projection allows to update the points of the zone to be modified according to the cutting line. The user can also draw inside any closed bounding volume by creating a separation inside the volume. The algorithm for separation is similar to the cut one except that we create a new surface at the cutting line. This allows a drawing inside and outside a volume. Our system has a parent-child hierarchical structure which enables us to display the inner or outer layers of any bounding volume as showed in Figure 4.

6. Uncertainty representation and navigation

Representing the uncertainty allows the architect to be able to show different versions for elements of the project. The representation of uncertainty and the navigation among the different options is crucial in the design of an architectural project. The chosen solution is to set up a grid of levels of gray that represents the potential deposits of some of the user strokes. The user can create local potential fields (calculated

from the field function of [CH01]) around a stroke of variable width. In case of areas of uncertainty, displacements of a stroke towards strong local potential fields is possible. The stroke is implemented as a mass-spring system attached to strong potential fields, enabling it to be positioned partly on one stroke and partly on another one as illustrated in Figure 5.

7. Results and Evaluation

7.1. User study

The purpose of this user study was to verify if the prototype meets the criteria imposed by the architects. A first prototype was tested by 6 professionals of the SCAU agency: 5 architects and a textile and material designer. Each session lasted about 15 minutes. Figures 6 and 7 present some architects creations realized during the user study. The uncertainty could not be tested during this first user study. The experimentation phase was composed of three stages:

1. explanation of the concept and demonstration of the prototype,
2. learning phase,
3. free drawing or exercise.

Indeed, for the last stage, examples of architectural projects were shown to the participants as inspiration. During the last step, the system was regularly saved as well as screen shots taken. At the end of the session, the user was asked some questions to validate or refute the criteria and was able to express free comments.

7.2. Results of the user study

In general, the architects found the prototype very interesting. This system was perceived as a prototype of "augmented paper" that could be used in the design phase. The preservation of the hand's gesture in the stroke was appreciated by most of the users. Being accustomed to working on software that vectorize the stroke, the designer found it interesting to keep rough strokes. After necessary explanations on the functioning of the different actions, the handling was rather

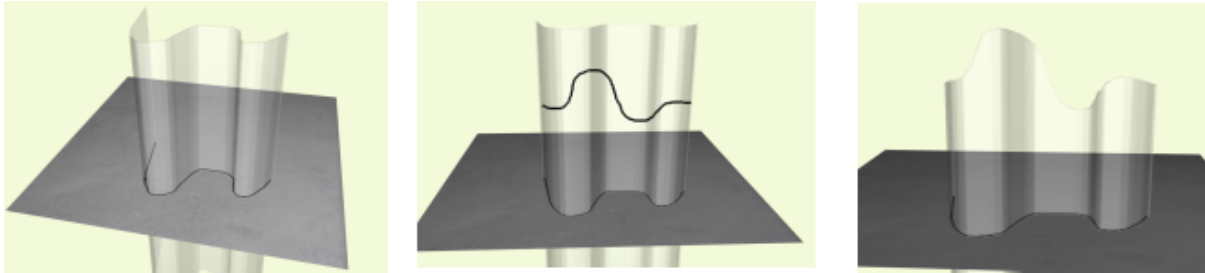


Figure 3: Illustration of the cut of a volume

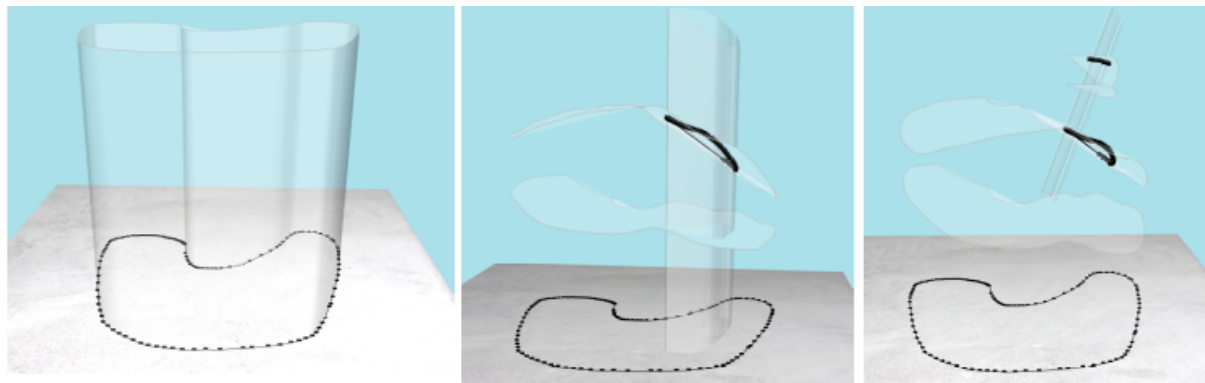


Figure 4: Illustration of the display of the inner layers : outer layer (left), first inner layer (center) and second inner layer (right)

direct. The architects assimilated in a few minutes the operations which allowed them in less than 15 minutes to realize their first production. On the other hand, some actions need to be done in a particular order, errors occurred when the latter was not respected. A longer learning of the prototype will solve this problem but the architects highlight that the handling was more immediate on this system than on digital softwares. No user had difficulty with the navigation. Figure 8 illustrates a validation rate representing the result of the survey submitted to the participants after their session.

7.3. Other results

In addition to the user study, Figure 9 illustrates some creations realized on our system.

8. Conclusion

The design phase of architectural project was “forgotten” from the provided tools. In our work we advanced towards meeting the architects needs. Based on these criteria, we were able to propose a method that is a new 3D interactive canvas concept with the following contributions:

- the recursive creation of nested bounding volumes,
- display and interaction in "onion peel" of semi-transparent layers,
- the representation of uncertainty with the ability to navigate between the lines of a line on-track,

then a first prototype of answer. Being able to represent the uncertainty and navigate among different option is a real improvement in conceptual design and can be very helpful for designers at early stages of design. The user study validates the coarse to fine approach, the freehand drawing and the handling was considered more immediate than on the industrial softwares.

There are still many ways of improvements for our method. Firstly, it does not allow the user to draw on multiple objects (plan or bounding volume) at a time. Indeed, at the end of a gesture of drawing, the stroke is attached to a single object that becomes its parent. Allowing to go beyond an object or the possibility to draw on several objects (plan or bounding volumes) would require recording all of these objects in a list and break the stroke into pieces with respect to the object on which they are drawn to perform actions on every objects.

In addition, in future work, the handling could be improved by combining sketches and sculpting gestures.

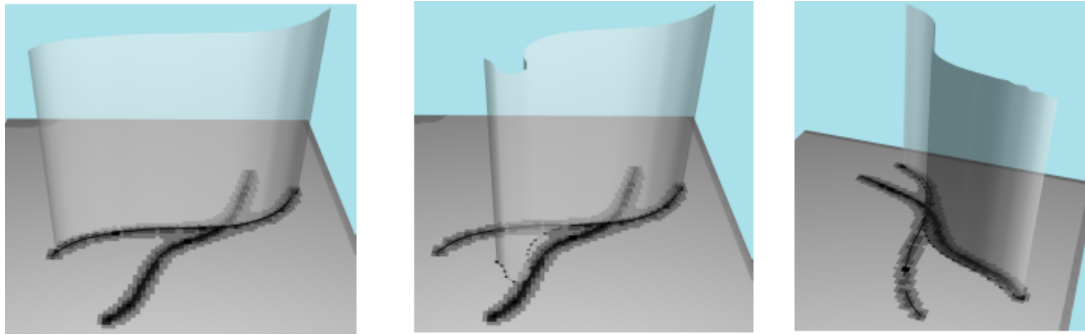


Figure 5: Displacement of a stroke towards strong local potential fields

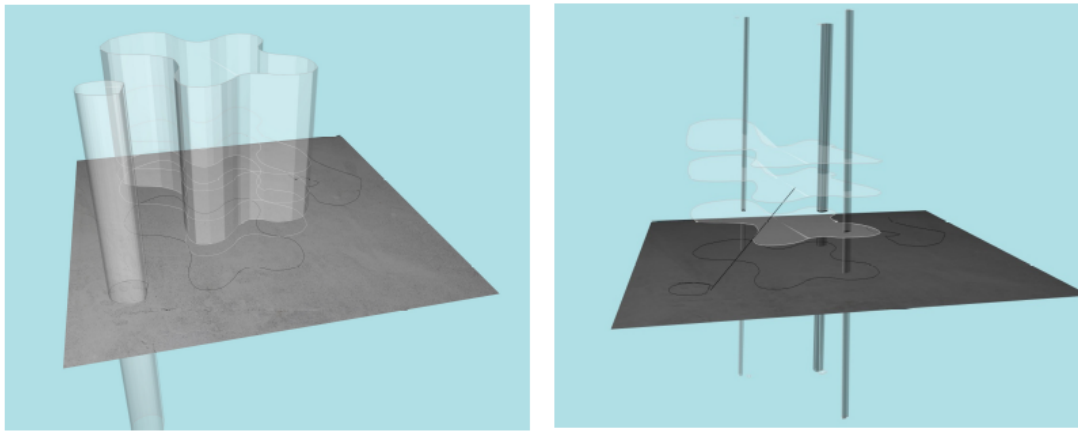


Figure 6: Example realised by an associate of the SCAU agency

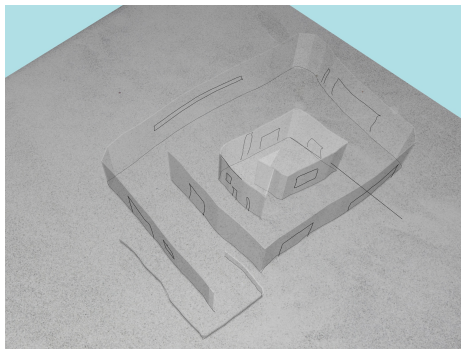


Figure 7: Example realised by an architect and PhD student in architecture of the SCAU agency

	Coarse to fine design	Freehand drawing	Immediate handling	3D Navigation
Validation rate	100 %	100 %	66 %	100 %

Figure 8: Sum up of the survey submitted after the user study

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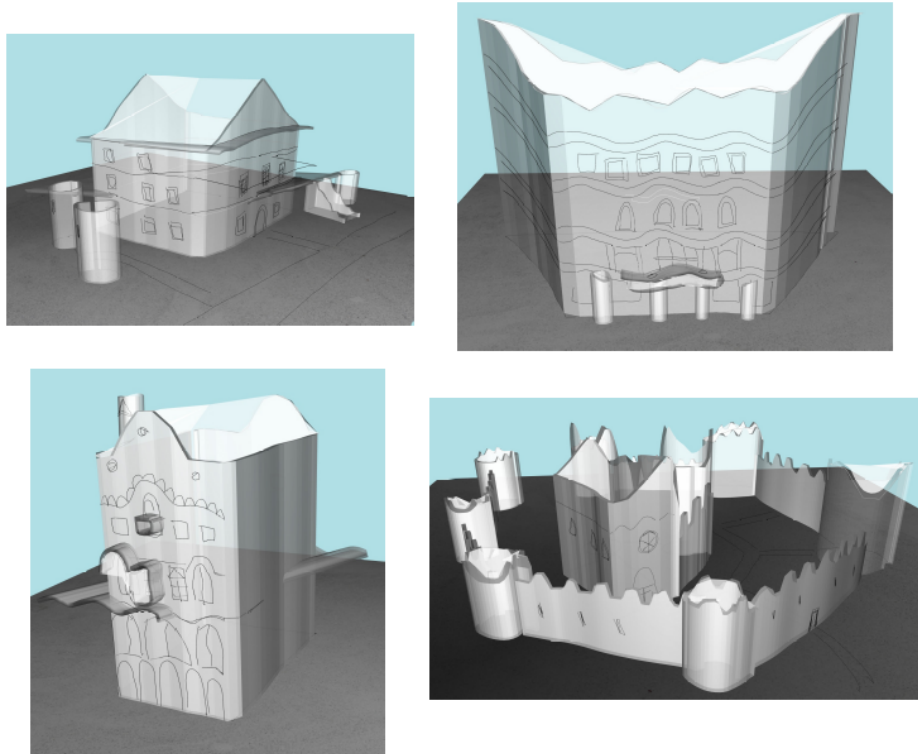


Figure 9: Creations realized with our prototype

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