Shaping the Place - A Digital Design Heuristics Tool to Support Creation of Urban Design Proposals by Non-Professionals

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Abstract

This paper is exploring a solution to foster civic engagement in urban design projects by applying the concepts of creativity to ICT tools. We propose a framework to support interactions between non-professionals and professionals that will ease the understanding of urban design and creation of design proposals for non-trained people and, on the other hand, offer valuable propositions and inspiration to experts. This make tool should have the presented creativity affordances known as fluency, flexibility and originality during the divergent phase of the creation process. We propose to implement a 3D collage metaphor to facilitate creative expression with 3D models. An underlying technical challenge of our application is to provide an interactive 3D mesh cutting tool to help users to express their creative potential in urban design projects. We present a non-exhaustive survey of mesh segmentation and cutting methodologies and finally, first results of implementation of a cutting algorithm.
Keywords: Urban design, creativity, Co-Design, 3D modeling, 3D collage.

1. Introduction

The traditional urban design and architecture approach is focussed on designing for end-users, and the traditional urban design tools for making buildings, plans or programmes are centred on professional users. Non-trained public may not fully understand the meaning of the output models. Issues such as scales, space constraints, usability of some spaces on a typical urban design model are difficult to grasp by a non-professional. Therefore, professionals use specific visualization tools to explain the idea to the client such as digital and material 3D models on various scales or fly-trough animation videos.

Pressing demand of citizens for increased involvement in city planning and urban design processes from early on stages requires appropriate tools supporting interaction between professionals and non-professionals. The tools should afford the possibility for non-professionals to grasp the abstract notion of space and its constraints and express their urban design ideas without specific drawing or modelling skills.

The aim of the article is to present a 3D generative environment with make tools in support of collaboration between professionals and non-professionals in urban design projects. The target is to support the creation of an urban design proposal by a non-professional who is not trained in understanding 3D space constraints and neither has drawing skills to express his/her ideas. We propose to implement a 3D collage metaphor (cut-and-paste) to facilitate creative expression with 3D models. An underlying technical challenge of our application is to provide an interactive 3D mesh cutting tool that will be intuitive and performant enough to help users to express their creative potential in urban design projects.

To achieve our objective, we will go through a series of methodological steps. First, we will define the creativity process, identify major steps and rules that must be respected to achieve a creative outcome and define qualities of supportive digital tools, as suggested by research literature on creativity. Second, we will review some existing digital solutions and evaluate their advantages and flaws against the creativity support properties. Building on these results, we will define functional requirements of the 3D generative environment being designed, discuss technical constraints and present first results of our prototype implementation.

2. Conceptual framework

2.1. Organizing creative process

The most cited definition of creativity process is that provided by T. Amabile: creativity is the process that leads to novel and useful solutions to given open problems [1]. Research on creativity highlights that several strategies can be used to achieve creative outcome: by transformation of existing products, producing novel associations and trial and error [8]. The latter is associated to learning, i.e. becoming aware about a new set of relevant elements, features, aspects which do not come merely from past knowledge [3]. It may become possible to link what seemed opposite in the past [2].

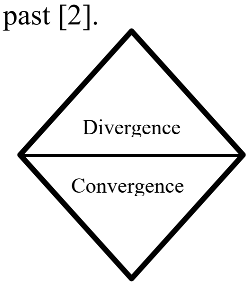

Fig. 1. Creative diamond (Guilford, 1950).

Psychological literature documents that creative act is not a singular event but a process, consisting of two phases, a generative and an evaluative phase [17]. Early scholars of creativity, such as J. P. Guilford, characterized the two phases as divergent thinking and convergent thinking [4] and related modes of thought, associative and analytical. Divergent thinking is the ability to produce a broad range of associations to a given stimulus or to arrive at many solutions to a problem (for overviews, see [1], [5], [6]). In contrast, convergent thinking refers to the capacity to quickly focus on the one best solution to a problem. The sequence of divergence and convergence is known as creative diamond.

Furthermore, it is widely admitted that creativity process is not an attribute of an alone genius creating ex nihilo. It occurs in collectives, groups and communities of people interacting and creating together, engaging in creation with objects, built environments and digital artefacts, over more or less long time. Therefore, it is important to provide appropriate methods and tools that orchestrate the collective creativity process around the divergence and convergence steps. More recent methodological contributions on creativity propose to organize the collective creations process in five major steps [7]:

- Task appraisal is centered on investigating what task to perform, how the task is related to others, criteria for appraisal for verifying the task is completed
- Divergence is about production of many ideas, imagining possible actions required to deliver the task
- Clustering is about categorizing the different actions
- Convergence is about evaluating, selecting the most promising options and refining them
- Reflection is about stepping step away and evaluating the quality of the execution of the task, both on process and output.

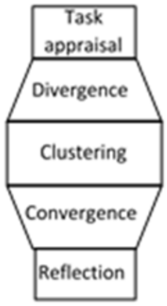

Fig. 2. Extended creative diamond, [7] Buijs & Meer van der, 2013, p. 14.

Relying on this work, we aim at designing a digital tool that supports three major steps – divergence, clustering and convergence in the context of collaborative creation of urban design proposals.

2.2. Creativity affordances in the context of urban design

Digital environment provides a seamless background affording creativity. The term "affordances" refers to properties and elements of environment that contribute to kinds of agent-situation interactions.

Applied to the context of urban design, digital tools should be able to support language with which non-professionals can express aesthetics of urban experience and unveil still unknown, ill- or undefined or unanticipated or latent citizen expectations, needs, feelings and emotions [41]. Traditionally, designers use make tools such as physical full-scale real and three-dimensional kits for space prototyping to facilitate the creative expression of non-professionals. They have proved to be efficient in collecting end-user's ideas and spurring design proposals from non-professionals; however, the cost of such prototyping turns to be high [42].

With new 3D-immersive technologies like virtual reality available at affordable cost it is now possible to overcome this problem. Different technological and methodological solutions have explored support visioning (see), narration (say) and forms of prototyping (make).

The Betaville Project [43] offers a "massive participatory online environment for distributed 3D design and development of proposals for changes to the built environment". Multiple actors can be connected to the same virtual city and "fly through it", model new structures, leave comments and engage a real-time discussion.

Basile and Terrin [44] present a mixed reality solution that uses a traditional urban design table on which a 2D plan is projected and physical objects representing build structures are placed on the top. The physical blocks are linked to 3D models that are displayed on a side screen that represents the real scene of the urban place being designed. Modifications on the table are visible in real time on the screen and furthermore, annotations or drawings can be added directly on the screen.

UN-Habitat [45] promoted the use of the Mojang AB's video game Minecraft to build propositions in a virtual city using the Minecraft tools. Feedback tools such as commenting produced design proposals are also available.

City I/O [46] proposes a table with an urban model on top build out of lego pieces. One can see the representation of the urban model in 3D on a screen that is directly linked to the physical model with extra textures added like trees and building shapes. Two modes of interaction are possible: one by adding/removing lego blocks on the table and seeing the change on the screen; or by interacting with the virtual model for softer actions like changing building colors or adding a comment. The virtual scene can be visualized either on a TV screen or on a mobile device using an AR application.

However, these solutions do not take into account the creative diamond steps. They build on an implicit assumption that citizens know how to express themselves in a creative way. Furthermore, the possibility to engage with 3D shapes remains limited: buildings can only be moved or built out of pre-set lego shapes; variations are achieved through changing colors or textures. To fill the gap, we ambition to offer a richer variety of interaction with 3D shapes and to support the 3 major phases of the creative diamond in the design of urban proposals.

2.3. Collecting generative features of 3D "Shaping the place" tool

The key functional requirements for the "Shaping the place" tool are derived from the analysis the creative process steps and include three key dimensions of creativity- flexibility, originality and fluency [24].

Supporting the divergence phase with a 3D collage tool

The proposed environment will stimulate creative expression and imagination through the bisociation strategy – starting from ready-to use models and shapes users can recombine them to create new shapes and designs. This will be achieved with the metaphor of collage – cutting and assembling heterogenous elements and parts of existing models into new 3D designs.

Interaction with 3D models occurs in "giant in a small world". The interface would provide a "3D collage" tool palette to alter predefined 3D models. Users should be able to access a library of 3D models and scenes, select a model and manipulate it. For example, they should be able to select and cut a part of the model and rework it – rotate, resize, merge with another model to obtain a completely new model. Therefore, a rich variety of creation possibilities can be explored through combination and making. In the divergence phase, no space constraint is imposed in order to support fluency and originality of design proposals.

In addition, the tool could stimulate flexibility of creation, that is, number of different perspectives on the same shape by offering components and models which have ambiguous meaning and are subject to personal interpretations

Collaboration is supported thanks to the use of a shared and intuitive interaction environment, (for example, a shared touch screen or table). Thus, participants will be able to engage with the digital content with natural gestures instead of focusing on operating computers with a mouse and keyboard.

Supporting the clustering phase with visualizing, sorting and ranking tools

Users should be able to see the design proposal they generate in real-size, feel the atmosphere and live the experience of the place to realize the effect of their design decisions. They should be able to give their assessment of the utility and usability of the proposed design as a whole or of selected parts of it.

Back to top-down view, users should be able to see the list of existing proposals, sort and rank them in order to select the most preferred option. Ranking metrics could include, for example, utility and originality – degree of newness - of the proposals.

Supporting the convergence phase with integration of space constraints

In the convergence phase, users should be able to refine the selected proposal. This is achieved by a two-fold approach. First, the 3D collage tool is redeployed to stimulate variations of the main design model. In the divergence phase, variations are rather achieved through experimentation with textures, colors and refinements of parts of the main model. Second, space constraints inherent to any urban design project are included in order to produce realistic proposals. Here, the challenge is to select a degree of constraint that does not break fluency and at the same time, provide sufficient level of detail. Different level of constraint could be envisaged. For example, the basic level of constraints will include size and proportions. More advanced levels could include legal norms, technical requirements and budget limitations. This will require rich support from professional modelling tools.

Supporting fluidity of the whole creation process across the three steps

The prototyping cycle should be quick. End-users should experience creation of urban models through design, review, trial and error experimentations and variations. It implies, created and experienced digital artefact should be saved and redeployed during future sessions, thus, making available mindsets by providing "time travel" back and a history of creative production.

2.4. Technical implementation

Literature review of 3D mesh cutting/segmentation techniques

We aim at implementing a collage metaphor that would reproduce the cut-and-paste paradigm borrowed from the manual human operation: cutting a piece of paper and paste it somewhere else to make original propositions. This metaphor is also well known in ICT tools as text editors or 3D modelling software. To answer to the first part of the problem, cutting, our application shall use an interactive methodology. According to current state of the art, we have two viable solutions: mesh segmentation and mesh cutting.

Mesh segmentation

Mesh segmentation is about identifying, automatically, semi-automatically or manually, certain parts (or regions) of a model. During the last decade, it has been a challenging field of research regarding many applications in computer graphics such as medicine, art, clothing design, texture mapping, 3D scene analysis, 3D model recognition or CAD and digital mockup softwares. Research effort has been made on automatic methodologies that provide the closest segmentation from a human point of view and more recently on co-segmentation methodologies for 3D models clustering into semantic parts [25] relying on machine learning algorithms to perform better over time.

Surveys have been conducted concerning existing mesh segmentation methodologies [26]–[28]. They offer an overview of the vast variety of techniques implemented so far, which are using one or more algorithms relying on several geometrical attributes of the mesh. According to Shamir [27], who defines segmentation as an optimization process(développer), methodologies can be classified as part-type or surface-type. The most common, part-type segmentation, consist in decomposing a shape into sub-shapes corresponding to relevant parts from a human perspective. It relies on the use of both volumetric attributes and surface related attributes. The purpose of surface-type segmentation is to find similarities between groups of faces in a model by taking advantage of surface-based geometric properties such as curvature or dihedral angle.

Segmentation is about wisely choosing the mesh attributes (or geometric criteria) that will be used as inputs for a segmentation technique, depending on the application. Attributes are geometrical characteristics of 3D objects that will determine how to cluster mesh elements (vertices for example). Two different methodologies aiming at different applications can possibly use the same attribute but in different manner. Here is a non-exhaustive list of geometric criteria that can be used:

- Geodesic Distance / Geodesic Distance to base / Average Geodesic Distance
- Dihedral Angle
- Convexity
- Shape Diameter Function
- Curvature
- Edge Length
- Symmetry
- Motion Characteristics

Generally, part-type and surface-type segmentation are not designed for the same applications, however there are some situations where semantic parts are used by surface-type segmentation to identify geometric shapes like spheres and planes for instance. The following table gives an overview of the applications depending on the segmentation type:

Table 1. Different applications of part-type and surface-type 3D mesh segmentations.

Segmentation type	Part-type	Surface-type
Applications	• Modeling by assembling paradigm: create new shape from existing ones • Shape matching/retrieval • Semantic identification • Collision Detection • Computer Animation • Morphing • Object Skeleton Generation	• Texture Mapping • Remeshing • Simplification • Morphing • Ray-Tracing • Mesh Compression • Collision Detection • CAD • Reverse Engineering • Watermarking

Theologou's survey added several classification characteristics as the type of geometric criteria, the number of objects used as information sources, the type of feature and most relevant for us the user involvement. What can be learned about user involvement is that most of the methodologies developed so far are automatic or with a minimal parametrization required by the user. For instance, some parameters as the number of segments to be generated or seed points are asked to the user before processing the segmentation.

The main segmentation methodologies have been grouped by [28] as follows:

- Clustering
- Region growing
- Surface fitting
- Topological
- Spatial Subdivision
- Spectral Analysis
- Boundary Detection
- Motion Characteristics
- Probabilistic models
- Co-Segmentation

It is important to notice that some techniques are shared between groups, e.g. Randomized Cuts [29] is categorized boundary-based methodology but includes a clustering technique.

Interactive segmentation methodologies require a significant contribution from the user. Boundary detection methodologies, can be applied by using a mouse stroke to manually define boundaries between segments. The main challenge here is to find the sequence of edges with least cost that fits best to users' stroke. Other methods [30], [31] use region growing methodologies to let user sketch on a mesh and optimally segment the concerned region. To perform cuts, fully interactive methodologies propose an interface tool (stroke, scissors…) to provide an experience as close as possible to the real action of cutting. In the beginning, interactive tools enabled users to draw a cut path on a mesh but with the need to rotate the model to finish the loop. Later solutions have been found, using a geometric snake for instance, to compute the background cut and close the loop automatically.

[33] approached the problem of an easy to use tool to support untrained users to create detailed 3D models through simple interactions: 3D models' segmentation using a painted "stroke" metaphor. A best fit cut is proposed to the user who can refine it as he wants. A vast 3D model database can be queried to retrieve similar shapes based on a selected one and finally, an assembly tool to ease user's creativity. This prototype fits several applications as education, art, digital mock-up or entertainment and perfectly correspond to the divergent phase of the creativity diamond. [32] proposes a similar solution but without the 3D model database. It is a user-centred tool for non-professionals, which let them manipulate 3D objects

focusing on the cut-and-paste operation. Therefore, it uses a boundary based segmentation operator employing a graph-cut algorithm coupled with a snapping operator, which combines relative positioning and blending to connect meshes in a graceful way. Another interaction metaphor is employed in [34]: a single mouse click on the mesh where the cut is desired will trigger an automatic definition of a segment, according to a configurable circle defining the precision of a cut. It can be classified as a semi-interactive tool due to the automatic segmentation phase.

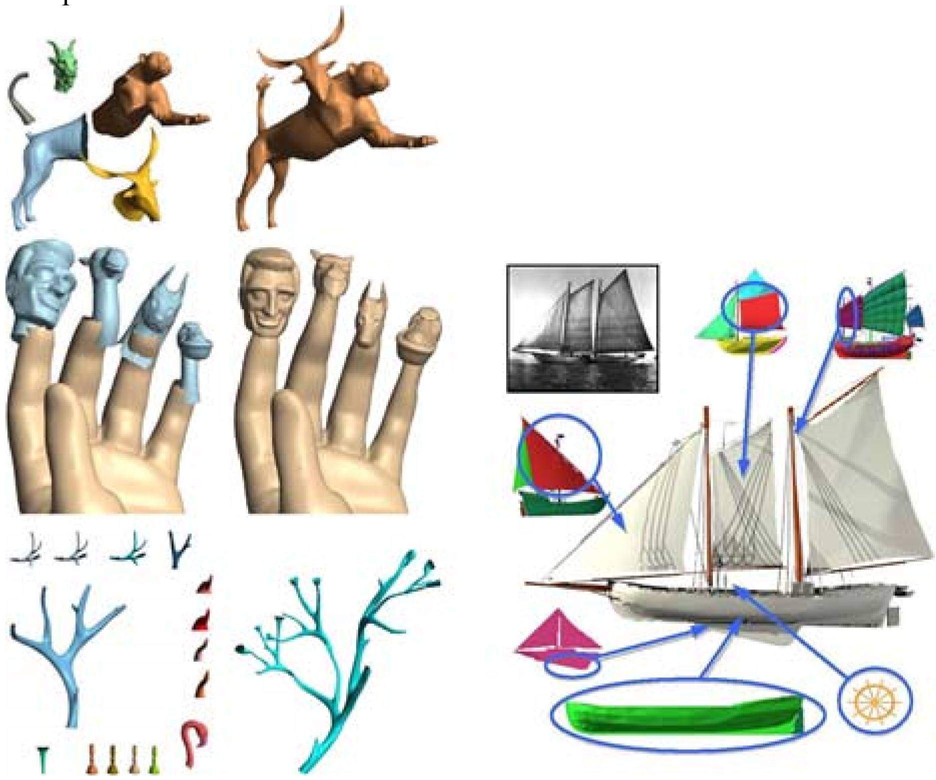

Fig. 3. Left: SnapPaste [32], right: Modeling By Example [33] [32], right: Modeling By Example.

Finally, performance evaluation frameworks [28], [35], [36] have been done using different datasets composed of multiple classes of 3D models. Nevertheless it is still a challenging problem to evaluate segmentation since it depends on user's interpretation. We can understand from these frameworks that there isn't yet a segmentation algorithm that performs best with every type (or class) of models. For that reason, there are many different solutions depending on the application.

Virtual mesh cutting

Mesh cutting (also referred to as virtual cutting) is mostly focused on surgery simulation and computer animation to perform real-time cutting of deformable bodies. Most of work done until today has been driven by image processing and applied to the 3D world. Virtual cutting can be defined as a controlled separation of a 3D model with a virtual tool (lasso, brush, stroke, scalpel…). Generally, this separation is made in real time and considers material properties of the object to predict, for example, tissue response. It implies the use of a rendering engine and the computation of motion equations. Our tool is not affected by the motion problem. Nevertheless, the surveys done by [37], [38] are interesting to analyse.

They offer an interesting review of cutting techniques, remeshing techniques and cutting tool representations. The first issue of virtual cutting is the computation of the cut path which is highly dependent of the cutting tool. According to [37], the path can be defined by either using seed points, hence the path is automatically determined by a linking algorithm (Dijkstra's shortest-path, geodesic distance or Euclidian distance), using a predefined shape to intersect the mesh or using a virtual tool composed of several primitives to manually define the cut path. The issue of the moment the cut is performed is not treated in this paper. In our methodology, the cut is always processed after the definition of a cut path and never in real-time. The second issue is about the effective cutting action. [38] identified six different techniques for incorporation of cut into meshes: element deletion, splitting along existing element faces, element duplication, snapping of vertices, element refinement and combination of snapping and refinement.

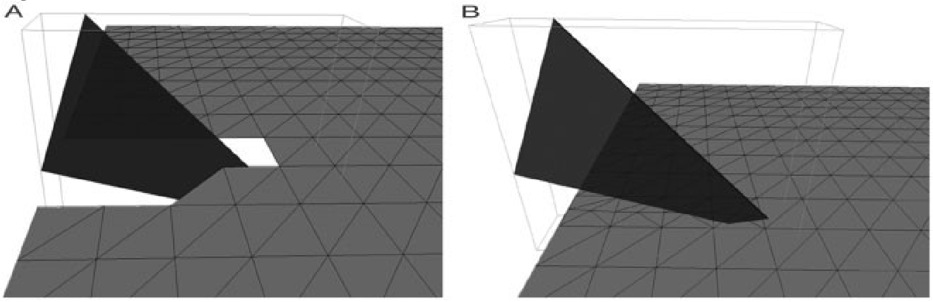

Fig. 4. Different methods for incorporating cuts into a tetrahedral mesh (a triangle mesh in 2D), J. Wu [30].

These techniques can be classified in two different parts: techniques that remove the intersected primitives and techniques that re-mesh the intersected primitives [37]. Figure 4 and 5 illustrate the classifications presented above. The choice of the technique will mostly depend on the need of the application since some will create jagged surfaces or ill-shaped(deformed) elements. According to [38], element duplication provides the best trade-off between both issues.

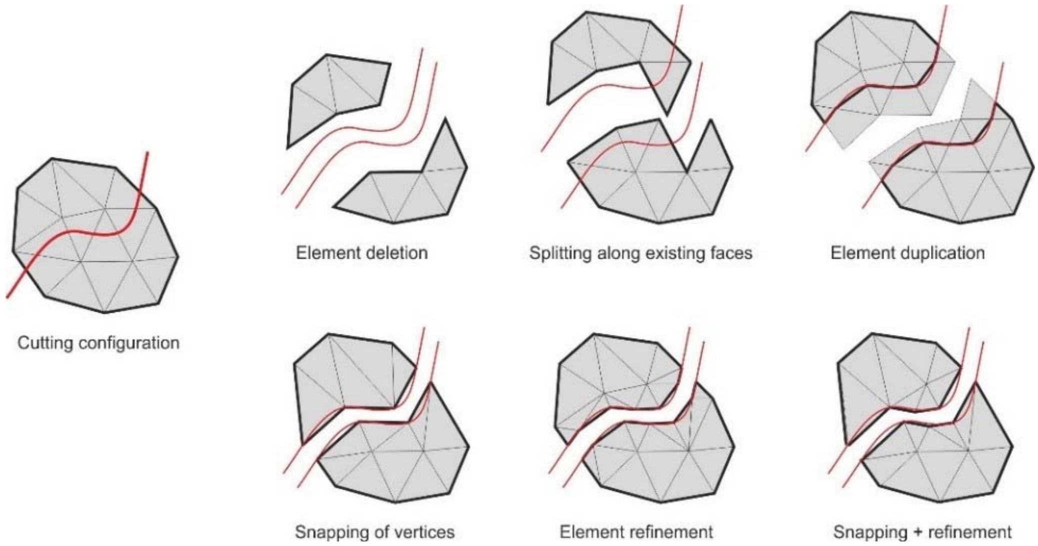

Fig. 5. Handling of re-meshing: (A) removal of intersected primitives; (B) re-meshing the intersected primitives », C. Bruyns [29].

3. First results

Our proposition aims to provide both interactive segmentation and interactive cutting tools to the user. As a first result, we present a trivial mesh cutting algorithm that intersects a user stroke with a triangle mesh to perform a cut separating the mesh in two parts. J. Mitani [39] wrote a paper that highly fits with our problematic except that it only cuts the front part of the model. Our application needs the model to be separated completely. Furthermore, our subdivision algorithm will differ from Mitani's as it will accept on-face-vertices (a vertex inside a triangle but on not on an edge) in its cutting line.[39] offers a solution that highly fits our problem except that it only cuts the front part of the model. Our application needs the model to be separated completely. Furthermore, our subdivision algorithm will differ from Mitani's as it will accept on-face-vertices (a vertex inside a triangle but on not on an edge) in its cutting line.

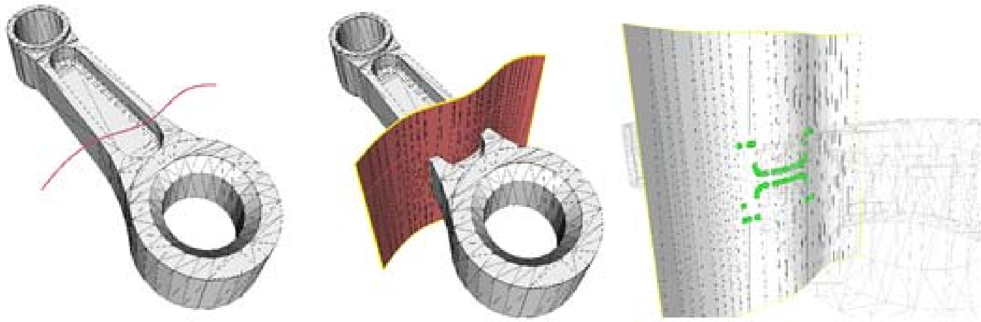

Fig. 6. Left: user's line is in red. Centre: The triangulated surface generated from the line. Right: The computed intersection points.

We propose a triangulated mesh cutting algorithm based on the intersection between a user sketch and the targeted model. The cut is not computed in real-time but after the user stroke is done. As illustrated in Figure 6, scenario is the following: user draws a line on the desired element to cut, then a triangulated surface is generated from this drawing that intersects the shape with its current position. Finally, the cut is computed by looking for the intersection points between the target model and the surface, creating two separate sub-meshes. The cut path is determined by computing a polyline P (set of edges) according to the face-edge intersections points of both meshes. We represent the polyline as a set of faces F_i containing its neighbour faces and a set of n intersection points, or portion of polyline, P_(i...n). Once the polyline is generated, we start a subdivision process to link the intersected faces of the target mesh with the intersection points. Then, two separate sub-meshes are created for rendering.

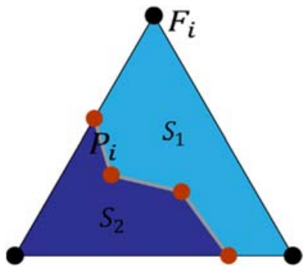

Fig. 7. An intersected face F_i divided in two sub-surfaces S_1 and S_2 according to and intersection line P_i.

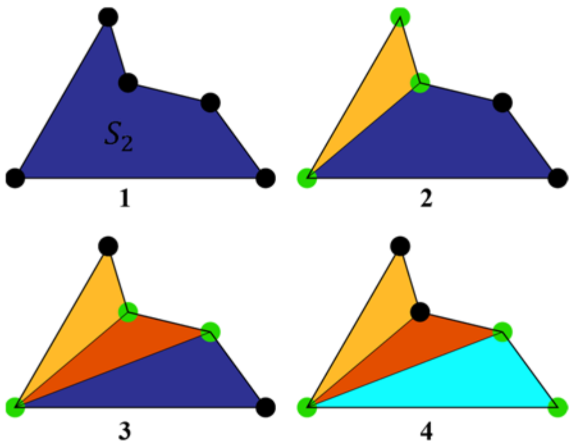

Fig. 8. Illustration of the subdivision process for one surface.

Subdivision

To subdivide the mesh through the polyline we use the following technique: inside an intersected face F_i we observe the different surfaces created by the portion of polyline P_i (Figure 7). As described in Figure 8, for each sub-surface S_i composed of more than 3 vertices, we create a new face with three consecutive vertices and so on until we have only triangles. This algorithm will sometimes result in the creation of degenerate triangles, which are triangles with very small surface often with three collinear or almost collinear points. To avoid this, we apply a complementary step after subdivision process which will deal with degenerate triangles. Ideally, the area of each new triangle needs to be check to not be under a

certain threshold, but it would be too consuming in terms of calculation. Hence, we decided to check the angles of the triangle with respect to a threshold and delete the face F_i if the angle is under the threshold.
The subdivided triangles are not perfectly equilateral which will lead to a rough deformation of the manipulated object. We did not determine it as a major problem since the urban design propositions made by non-professionals dot not need high-quality models in comparison with designers and architects' propositions. Nevertheless, it is an interesting challenge for future work.
Finally, to realize the visual separation of the mesh we duplicate the points of the polyline, generate two separate meshes and move them aside.

Application

In an application scenario, we will use a 3D game engine as Unity to give to the user an interactive interface on a computer to draw the cutting line. Then we intend to make the computation of the cut within an external open source library named CGAL for performance-related reasons. Currently, we use a 3D geometry software XDS [40].

4. Conclusion and next steps

In this paper we presented a methodology based on creativity affordances to foster public participation in urban design. A first cutting algorithm has been presented to answer partially to the 3D collage metaphor. It will be reviewed in further work and replaced by an algorithm relying on bounding boxes for the calculation of intersection points. Furthermore, functionalities will be added to the tool as mesh blending and automatic segmentation to provide more creative interface to the user as well as more immersive interfaces working with virtual reality headsets and touch screens.

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