ExquiMo: An Exquisite Corpse Tool for Co-creative 3D Shape Modeling

Abstract

We introduce a shape modeling tool, ExquiMo, which is guided by the idea of improving the *creativity* of 3D shape designs through *collaboration*. Inspired by the game of Exquisite Corpse, our tool allocates distinct parts of a shape to multiple players who model the assigned parts in a sequence. Our approach is motivated by the understanding that *effective surprise* leads to creative outcomes. Hence, to maintain the surprise factor of the output, we conceal the previously modeled parts from the most recent player. Part designs from individual players are fused together to produce an often unexpected, hence creative, end result. However, to maintain the functional plausibility of the final shape, our tool must encourage a certain level of coherence between the parts. We achieve this by first defining an end goal which conveys the targeted shape category, and then revealing a small portion of the connecting regions of any adjacent parts to a player during his/her turn. We demonstrate the effectiveness of collaborative modeling for both man-made and natural shapes. Our results show that, when compared to models designed by single users, multi-user collaborative modeling via ExquiMo tends to lead to more creative designs.

Keywords: Creative Shape Modeling, Collaborative Design

1. Introduction

Creativity is a wonder of the brain. It broadens the human imagination, thereby spawning innovations ranging from surreal paintings to unheard melodies. In computer graphics, where emerging developments in 3D fabrication technologies are changing the face of shape design, creative modeling is beginning to play an important role. Most of the prevalent creative modeling tasks are driven by computational tools [1] operated by humans; hence giving rise to an intriguing question [2]: "Apart from playing the role of a mere tool, can machines assist or *inspire* humans in a creative endeavor for the generation of geometric forms?"

Although this question has not been extensively studied in previous works, inspired modeling methods such as explorative modeling [3], example-driven synthesis [4], and evolutionary design [5] have attempted to develop computational tools to assist human creativity. However, the creativity level of the output produced by these inspired-modeling approaches is limited. To understand the reason that limits the creativity of such tools, it is important to define what creativity is. Jerome Bruner [6] terms effective surprise as the hallmark of a creative enterprise. Oftentimes, the output produced by the inspired modeling methods resembles the models taken as inspirations; hence limiting the effective surprise.

In this paper, we introduce the use of *co-creativity* for 3D shape modeling, with the goal of producing effectively surprising, hence creative, geometric forms. Co-creativity is guided by the collaboration of multiple individuals who contribute to a creative endeavor. During this collaboration, ideas from each individual are fused together to produce unexpected results [7].

Our realization of co-creative modeling is inspired by the tabletop game "Exquisite Corpse" [8], which exploits human collaboration to produce a creative sketch or poem. In an Exquisite Corpse game, each player draws a particular part of a sketch in sequence, such that previous drawings are concealed from the current player to stimulate unexpectedness of the final outcome. However, a sufficient level of coherence should be maintained between each drawing. Hence, the overall goal is conveyed to all the players at the beginning of the game, e.g., the category of the object drawn, and vague hints of others' drawings may be revealed to the current player.

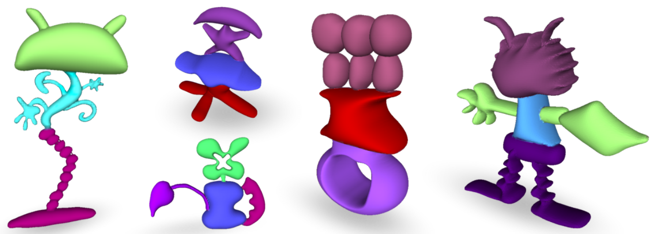

Figure 1: Collaboratively designed 3D shapes via ExquiMo, our modeling tool inspired by the Exquisite Corpse game, exhibiting an appreciable level of creativity. Different colors in each shape correspond to parts designed by different users.

In this paper, we introduce *ExquiMo*, an Exquisite Corpse tool for co-creative 3D shape modeling. Given an end goal and the number of players, ExquiMo first allocates one part to each player using a template. A sequential drawing process then allows each player to design his/her part. Here, the user is first asked to sketch the part in 2D, then a sketch-based modeling approach [9] is employed to produce the 3D shape part. At this stage, similar to the game of Exquisite Corpse, all the previous drawings are concealed. However, to further encourage coherency between the parts, hints are provided in the form of small portions of the connecting regions of any adjacent parts, which are revealed to the current player during the turn. Once all the parts are drawn in 3D, a part merging step is carried out to produce the complete composite 3D shape.

We demonstrate the creative potential enabled by ExquiMo with visual examples of man-made and organic 3D shapes produced through collaborative efforts between multiple players. It is important to note that none of the players are professional artists; they are all graduate students from engineering and computer science departments. Furthermore, we evaluate our approach through a user study that is conducted to compare shapes designed by single users to shapes designed collaboratively by multiple users. Under both scenarios, the users completed their designs using ExquiMo and they were provided with the same instructions and goals for the design: to be creative while ensuring that the produced final object would function as expected. For the comparison, a different set of users were asked to judge the creativity of the final designs while keeping in mind their functionality. Results of the user study are supportive of our hypothesis that multi-user collaborative 3D modeling via ExquiMo tends to lead to more creative designs.

2. Related work

Due to the ubiquity of applications that use 3D graphics, effective geometric modeling techniques have gained much attention over the past few years. Many interactive geometric modeling tools have been developed with a motivation of enabling non-expert users to create 3D models efficiently. Part-based modeling [10, 11], arguably the predominant modeling paradigm, allows a novice user to combine a set of parts taken from an existing shape repository to produce a new geometric form. Recent work by Chaudhuri, et al. [4] adopts the term *creative modeling*; their 3D modeling tool provides data-driven suggestions for suitable shape parts to the users so as to "stimulate" their creativity. With all the data-driven techniques, the conceptual design of the shapes comes from the user [10] or is possibly stimulated by machine suggestions [4], yet the parts themselves are obtained from existing models, limiting the imaginative capabilities of the users. Sketch-based modeling [12] allows the users to freely design shapes and their parts, but again, any creativity would come purely from the users themselves.

In our work, we are interested in how human creativity can be supported by the underlying modeling tool. Most of the existing works on shape modeling do not explicitly target the creativity of the synthesized shapes; hence the domain of creative modeling is relatively unexplored. One of the few works on creative shape modeling comes from evolutionary computing [13, 5]. However, to the best of our knowledge, none of the previous works exploit co-creativity to model creative and functionally plausible shapes. In this section, we discuss the most closely related work to ours in the context of creative shape modeling and synthesis.

Shape synthesis. When building large repositories of 3D models, it is helpful to use data-driven approaches, such as probabilistic models [14, 15] or template-based learning approaches [16] to synthesize novel shapes. Novelty here refers to producing shapes that are, up to some extent, different from the query shapes topologically or geometrically. Nevertheless, it does not directly target "creativity", which is the focus on our pursuit.

Shape blending. Another possible approach to creating novel shapes from a given set of geometrically and topologically varying query shapes is via blending [17, 18]. The blending could be controlled by a user [18], or the user can select the desired shapes from the resulting set [17]. A more recent work [19] introduces a low-dimensional procedural model for an object category to facilitate exploring the space of novel shapes by varying different parameters. More relevant to our work is the recent attempt to automatically design zoomorphic shapes through deforming and merging a man-made object and an animal model to suggest unusual, yet viable, designs to the user [20]. The above methods focus on utilizating existing shapes, whereas our focus is placed on creative modeling through collaboration.

Evolutionary design. Early works by Karl Sims [13] apply evolutionary computing to produce novel virtual creatures with some desired functionality. Several follow-up works [21, 5] in computer graphics have applied similar concepts to synthesize a set of "fit and diverse" shapes. Here, the focus on "diversity" attempts to stimulate creativity. In our work, we achieve creativity in shape modeling by combining the ideas of multiple users. The fitness or the functional plausibility is achieved by defining an end goal that encourages a coherent end result.

Collaborative design. To the best of our knowledge, our work is the first to introduce collaboration into the geometric modeling domain. However, the idea of collaboration is unintentionally used by some previous work through crowd-sourcing methods. PicBreeder [22], and EndlessForms [21], are two applications that provide multiple users to collaborate (or contribute) in generating novel images and 3D shapes by evolving a set of shapes produced by other users. In the work of Talton, et al. [23], the modeling activity of individual users can be learned as a distribution to construct high-quality alternative 3D models through exploring in a space of various models [23]. Although these systems offer collaborative environments, the users can only interact with already generated shapes. Conversely, we concentrate on providing the participants with more control on what they desire to create.

In the domain of human computer interaction, a number of methods have been developed to incorporate a machine as a colleague for collaborative design. Davis et al. [7] introduce Drawing Apprentice, a co-creative agent which co-operates with users in real-time on abstract drawings. We apply a similar concept into the geometric modeling domain. In contrast to their tool, the collaboration is performed between multiple human users in our approach and involving a computer partner in the framework is left for future work.

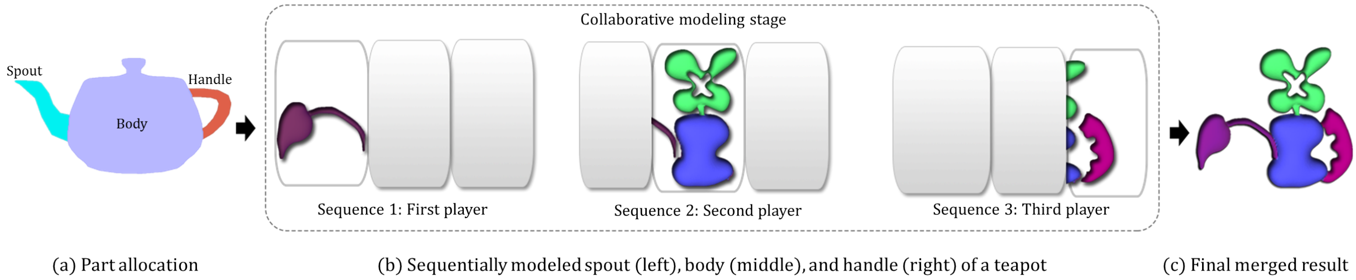

Figure 2: Design pipeline of ExquiMo. Initially, an object category is given and the parts are allocated to players (a). Sequentially, each player designs the allocated part in the form of a 2D sketch, which is then converted to a 3D part (b). Note that a player may receive a small hint for the previously designed part. Finally, the parts are translated, scaled, and merged to produce the final shape (c).

Figure 3: Three interesting sketches produced by the 2D Exquisite Corpse drawing game.

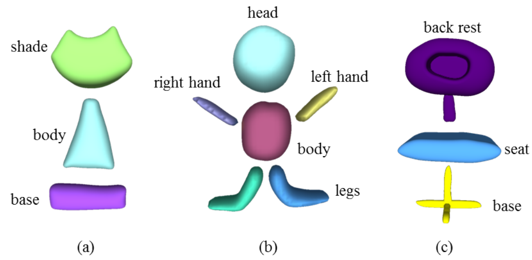

Figure 4: Examples of predefined shape templates, (a) a lamp, (b) a creature, and (c) a swivel chair.

3. Shape modeling via Exquisite Corpse

Our work is motivated by the idea that collaboration enhances, or contributes to, the creativity of one person. Collaboration as a factor of increasing creativity has been studied frequently in both sociology and design domains [24, 25]. As stated by Uzzi and Spiro [24], when multiple individuals contribute to some task, “diverse ideas are united together”, giving rise to creative end results. We build upon the game of Exquisite Corpse to collaboratively model a 3D shape while ensuring that the end result is creative and functionally coherent.

3.1. The Exquisite Corpse game

“Exquisite Corpse” is a multi-player game that showcases collective creativity by producing an extremely creative end result, let it be a poem, a drawing (see Figure 3), or a prose. In the poetic domain, the game proceeds as follows. First, an image of a scenario is shown to all the participants. The first player writes the first verse about the scenery in a piece of paper, and passes it on to the next player in line. All the players can only view the last word of the verse written by their predecessors, which ensures unexpectedness of each input. The lines of the poem are written in a sequence so that, once all the players have contributed, the end result would be a complete poem. The creativity of each person, and the fact that they are unaware of the input of the other players, contribute to the humorous juxtapositions, hence creative end results.

3.2. Collaborative modeling paradigm

We follow a similar technique to Exquisite Corpse when modeling a 3D shape in parts as a collaboration between two or more players.

End goal definition. Analogous to showing an image containing a scenario in Exquisite Corpse, we first define an end goal to encourage a certain level of coherence between the users. The goal can be the exact type of a chair (e.g., a swivel chair), a shape category (e.g., an animal), or an abstract shape (e.g., an upright shape with 3 parts). The number of players required to draw one shape is predefined and varies according to each shape category.

Part allocation. For each shape category, we predefine a template that provides a placeholder for each member from the set of semantic components that compose a given shape. An example of a template is given in Figure 4(a), where the lamp is decomposed into three semantic parts - the shade, body, and base. When a target has been selected, we retrieve its template and players are each allocated one part therefrom; each player will then use the modeling tool to produce their assigned part, taking turns according to a defined sequence (see Figure 2).

The modeling tool. Once each user is allocated a part, the game is started by the player who is allocated the first part. Each player draws a contour, or a less detailed sketch, of the allocated part during their turn, which is immediately converted to 3D prior to switching players. Since our goal is to encourage creativity while providing a simple tool that even novice play-

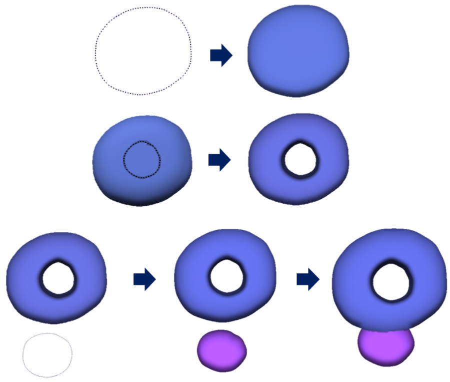

Figure 5: Three examples of the editing operators provided by ShapeShop that allows the players to model creative shapes. The operations are, from top to bottom in order, sketch to 3D conversion, CSG-based cutting, and part merging.

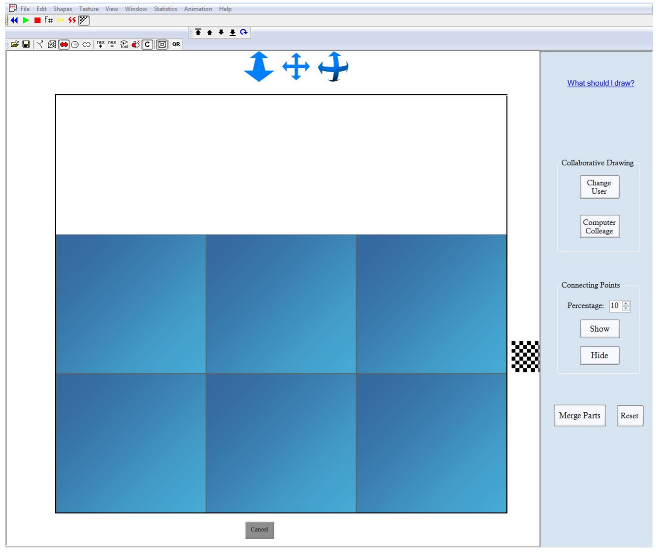

Figure 6: The user interface of our collaborative modeling tool.

ers can use, we use ShapeShop [9] as the foundation for our modeling tool, and make modifications in order for it to fit to our collaborative modeling workflow (as described under the subsequent steps). ShapeShop provides a sketch-based, 2D interface that then applies CSG-based cutting and blending operations to produce interesting 3D shapes with arbitrary topology, hence aligning with our stated goal of creative modeling. Few of the operations provided by ShapeShop, which were utilized by our modeling tool, are shown in Figure 5.

Co-creative modeling. When the first player draws the allocated part in 3D, our collaborative modeling tool provides an option to “change the user”, which conceals the currently drawn parts from the next player (Figure 2(b)). This technique of hiding the current design from the players contributes to the surprising factor of the output shape. However, parts drawn by different users may not align properly, resulting in implausible or non-functional shapes. Therefore, to encourage coherency, hints are provided in the form of small portions of the connecting regions of the adjacent parts, which are revealed to the user when necessary. With increasing coherency, the output shape may become less creative. To avoid this drawback, we restricted the user from revealing more than 30% of the adjacent part.

Part merging. At the very end of the game, once all the players complete their turn in designing the corresponding parts, the entire shape is unveiled, and a merge operation is performed by the last player to fusion the parts together. This merge operation consists of two key steps: (i) proper *alignment* of the two parts to be merged, and (ii) *blending* the aligned parts into one complete shape [26]. During the alignment step, our tool simply aligns the reflection symmetry planes of the two parts. The 3D parts which were created from the scratch almost always have the reflectional symmetry property; hence alignment by symmetry planes between two adjoining parts is natural and ubiquitous. If the user deems that a further alignment is necessary, the system then allows the user to manually perform the alignment by means of simple translation and rotation operations. When the parts are properly aligned, our tool utilizes the blending operations facilitated by ShapeShop, which implements parameterized Hyperblend [9] via a hierarchical BlobTree structure [27] to combine multiple parts into one shape.

The problem of part merging has been previously studied in the shape composition literature, such as the commonly used field based approaches [28, 26], part snapping [29] based on Soft-ICP registration [30], and boundary interpolation [31], those of which could be feasibly adapted by our work. However, owing to our focus on high-level creative modeling, as opposed to low-level part composition, we chose to implement a much simpler scheme as described.

4. Results and evaluation

In this section, we present results obtained by co-creatively modeling 3D shapes using ExquiMo. Studies were conducted in two stages. In the first stage, we conducted experiments using a set of participants who utilized the tool for collaborative shape modeling. In the second stage, we conducted a user study to evaluate the designs produced in the first stage. All the resulting models collected from the experiments and a video demonstrating the usage of our tool are included in the supplementary material.

Object categories. In the current work, as a proof of concept, we limit ourselves to six object categories: teapots, lamps, vases, swivel chairs and watering cans as man-made shapes, and creatures as an organic shape category. Note that creatures are the most frequently played forms in conventional Exquisite Corpse drawing games. For these target shape categories, we predefined a template consisting of three to five parts. The players are provided with the list of target categories to model, from which they make their selection.

Collaborative modeling. During the first stage of our study, we conducted experiments with 10 participants, who were asked to

Table 1: Statistics from the first questionnaire, which provide the percentage of votes received with respect to the level of collaboration. The three aspects considered for each shape pair were, creativity, functionality, and both creativity and functionality together.

Aspect	Single-user	Collaborative
Creativity	28.57%	71.43%
Functionality	64.89%	35.11%
Creative while functioning (C & F)	46.28%	53.72%

Table 2: Detailed statistics from the first questionnaire indicating the percentage of votes received for individually and collaboratively designed models belonging to each shape category.

Category	Aspect	Single-user	Collaborative
Lamp	Creativity	10.75%	89.25%
	Functionality	57.50%	42.50%
	C & F	39.24%	60.76%
Chair	Creativity	20.93%	79.07%
	Functionality	66.67%	33.33%
	C & F	41.03%	58.97%
Watering Can	Creativity	23.81%	76.19%
	Functionality	53.85%	46.15%
	C & F	27.91%	72.09%
Teapot	Creativity	25.19%	74.81%
	Functionality	76.92%	23.08%
	C & F	45.30%	54.70%
Creature	Creativity	38.17%	61.83%
	Functionality	53.85%	46.15%
	C & F	48.70%	51.30%
Vase	Creativity	44.32%	55.68%
	Functionality	75.64%	24.36%
	C & F	64.10%	35.90%

play the game of Exquisite Corpse in 3D using our collaborative modeling tool ExquiMo. The participants are graduate students in computer science and engineering who had a negligible level of experience in design (i.e., novice users). We now discuss the process we followed when conducting the experiments.

First, all the participants were conveyed the purpose of the tool, and the rules of the game (as mentioned in Section 3). They were asked to be "as creative as possible" when drawing the shape parts. Second, the participants were asked to choose one of the predefined target shape categories. A sketch (i.e. an outline) of an abstract shape belonging to the same shape category, with already labeled parts, is shown to all the players to avoid any confusion; see Figure 2(a). As the third step, each user was asked to *individually* model a shape from the selected category using the modeling tool, which was later utilized as the "single-user" design in our second stage. Finally, the players were asked to *collaboratively* model a shape for the selected category using our tool (see Figure 6). When merged, the resulting shape displayed a significant level of creativity as shown in Figure 1 and Figure 7.

Platform and timing. Our tool can be controlled by touch-enabled devices, providing easy interaction to novice users. However, in a situation where a significant level of unease was detected with the tool, the participant was asked to sketch their idea on paper prior to drawing on the computer screen, so that the imaginative capabilities of the user would not have been hindered by the unfamiliarity with the tool. During the modeling process, each player took at most 10 minutes to draw the allocated part, leading to a total game time of 35 minutes on average.

User study. We conducted two preliminary user studies with the shapes acquired from the previous experiments to prove the hypothesis that our collaborative modeling tool is effective in *improving* the creativity of shape designs. Each study contained two types of questions: quantitative and qualitative. Both studies were completed by 39 participants, majority of which again come from a computer science or engineering background, while a minority was from non-technical disciplines.

The first questionnaire consisted of three parts. In each part, the user was presented with a pair of shapes, where one shape was modeled by a single user, and the other was modeled by a collaborative effort. The pairs shown were randomly shuffled to avoid any biases. In the first part of the questionnaire, the user was asked to select "the design that is more creative", given the category of the shape. At the same time, to identify the factors that deem an object creative to humans, we asked the user to reason out his/her choice. Terms or keywords were not provided during the questionnaire, so as not to limit an individual's definition of creativity. The second part required the user to choose "the design that is more functional", along with qualitative feedback to specify the reason for their choice. The third part focused on both creativity and functionality together, where the user was asked to select "the design that is more creative, while remaining functional".

The statistics acquired from the first questionnaire (Table 1 and Table 2) show that the collaboratively modeled shape designs were found to be more "creative" by the users when compared to individually modeled shapes, over all the tested object categories. The most common keywords collected from the qualitative feedback can be identified as the factors that humans used to determine the creativity of the given designs. Out of the five keywords extracted from the study, "unexpected", "less ordinary", "imaginative", "attractive", and "non-symmetrical" align with the idea of effective surprise addressed by our work. Whereas the keywords "complex" and "more detailed" which are extracted from the responses deviate towards the careful

Table 3: Statistics from the second questionnaire, including the percentage of votes received for each shape category with respect to the level of collaboration.

Category	Single-user	Collaborative
Creature	28.89%	71.11%
Teapot	28.95%	71.05%
Lamp	34.21%	65.79%
Vase	57.89%	42.11%

thought players have given to designing each part.

However, in the second part of the study, the collaboratively modeled shapes were not categorized as being more "functional" majority of the time. Feedback from the qualitative study reveals that the users tend to select a model designed by a single-user as more functional due to its resemblance to a common, more familiar design. Perhaps more importantly, the collaboratively designed shapes were selected as more "creative while remaining functional" by the majority of the users over all object categories except for the vases, hence revealing users' preference with the collaboratively created models overall. Vases have a relatively simpler design when compared to other shape categories. Hence the user may give preference to simplicity of the design, over creative, yet somewhat complex designs, which may have been the cause for the higher percentage of votes received by the vases category.

In the second questionnaire, the user was presented with 6 to 8 shapes from one shape category, where half of the shapes presented were modeled individually, while the other half were modeled collaboratively. The user was asked to select "the top three shapes (in order) that are creative, while remaining functional". The statistics acquired from this questionnaire (see Table 3) shows the participants' preference for collaboratively modeled designs in most shape categories. Moreover, out of the four shape categories presented to the user, the designs that received the most votes consist of collaboratively designed shapes, which are included in Figure 1.

After combining the responses received from both studies, we conclude that our hypothesis is valid for the categories of shapes being tested; hence, the designs produced using our collaborative modeling tool is effective in improving creativity, while remaining functional compared to the designs produced by a single user.

5. Discussion, limitations and future work

In this paper, we present a modeling tool, ExquiMo, which assists users in designing creative 3D shapes. We build upon the game of Exquisite Corpse, which is based on the idea of collaboration. It combines the creative capabilities of multiple players by allowing them to *co-creatively* design distinct parts of a given shape. We increase the unexpectedness of the end result by concealing the parts already being modeled, whereas the coherency is maintained by revealing small portions of any adjacent parts to the part being currently modeled.

Limitations. As a proof of concept, our tool was tested with only six shape categories. However, one of the limiting factors of ExquiMo is its inability to model shape categories containing parts that are spanning in multiple directions. In such situations the user requires the shape to be viewed in different angles for the sketch-based modeling process, revealing the entire set of parts modeled by the previous players on the same canvas. To overcome this limitation, the tool can provide an option for the players to draw in different canvases and combine the results at the end of the game. Our tool is limited by the capabilities of the underlying sketch-based modeling approach as well, such as the requirement for smooth and closed 2D contours [9]. Currently, our tool is incapable of allowing users to collaborate remotely. Hence, all the users should be present at one place during the game play.

Future work. The approach we have introduced in this paper is a preliminary attempt to bring in collaborative design to the creative modeling domain. Hence, there are many potential areas to be explored when extending our modeling paradigm. First, our current rudimentary part merging scheme can certainly be improved with a more sophisticated state-of-the-art alignment and merging scheme, which may require less interaction from the user. Furthermore, a more detailed analysis of shapes can be carried out as future work to identify the aspects of the models that define the designs as creative. Our work attempts to gain a certain level of functional stability by means of hints (i.e. connecting points). However, it may be helpful to study the impact of hints on both functional stability and creativity alike.

Next, moving one step forward, a human-machine collaboration [7] can be considered apart from a mere human-human collaboration. Introducing such a blended collaboration may help bridging the gap between generative systems, such as 3D shape synthesis applications [15], and creativity support tools for geometric modeling [23].

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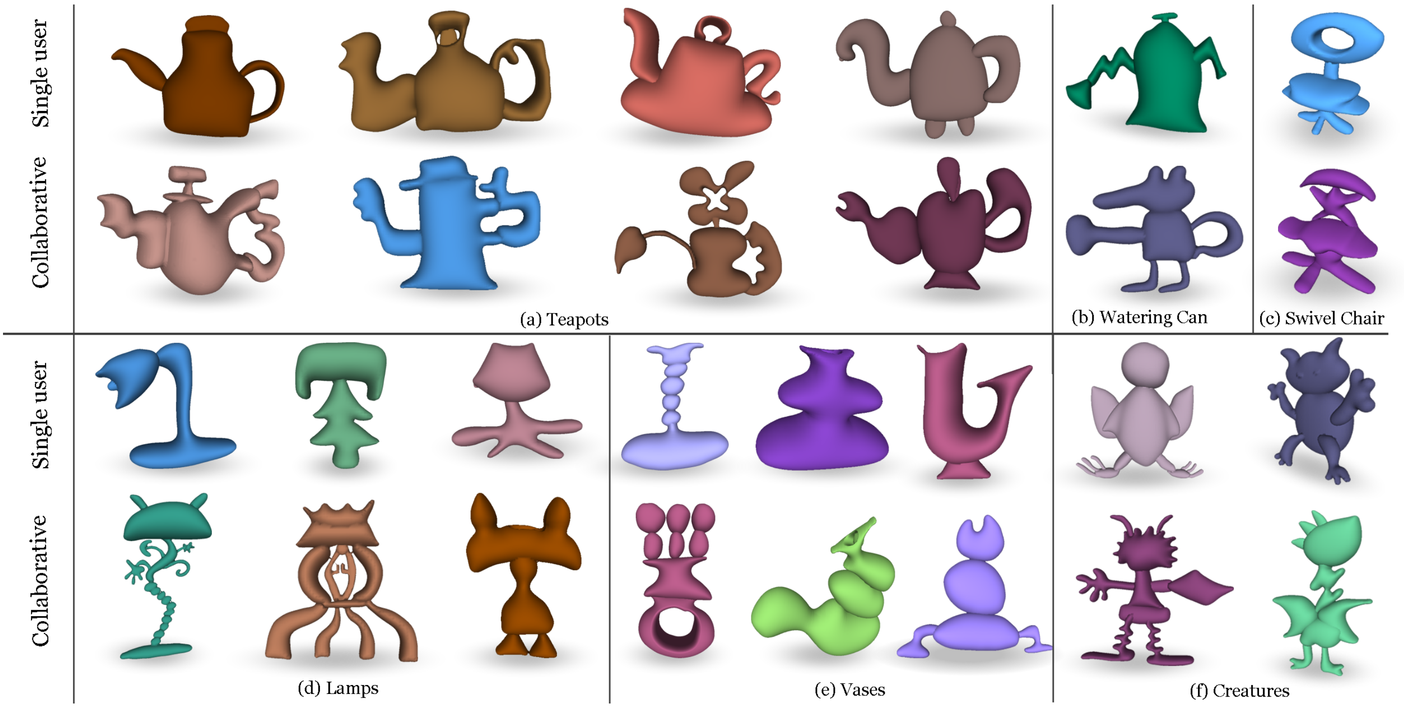

Figure 7: A sample of the shape categories modeled by a single user (top row), and multiple users (bottom row) using our tool, ExquiMo. Collaboratively modeled shapes were voted as "more creative, while remaining functional" by the participants of the user study.

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