Creating 3D shapes by time extrusion of moving objects

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Abstract

The idea behind this paper is to investigate forms created as “time imprint” of moving 2D and 3D objects through space, while simultaneously changing their transformations: translation, rotation, scaling, etc. The movement develops along a path that can be either assigned or random. In this manner, the movement, only possible with the time component, remains “frozen” in the form of a solid model. Hence, we may assume time as a modeling tool, which connects and unites successive movements of an object into a whole.
The procedure in question is visualized with Blender 3D animation and modeling tools. The render examples visualise time based extrusion of the object’s random transformations in 3D space. The transformations are randomly generated and controlled by noise function.
The given modeling method provides simple and quick, but very intriguing options for creating a wide range of shapes that can be used in various areas of art and design: from graphic design, to a novel way of sculptural and even architectural design. These forms may convincingly represent natural and bionic forms, e.g. hair strands, vegetation growth, etc. The possibility of 3D printing enables the physical materialization of these shapes suitable for further processing and use for decorative purposes, such as architectural ornaments or jewellery.

As an integral part of the research, we include animation which shows the method of generating shapes in the described manner.

1. Introduction

3D modeling of solid figures can be performed as a CAGD or as a procedural modeling. Today's computer software enables both modeling methods to be about equally elegant, fast and convincing. If we desire to model some simple geometric form, the complexity in the procedures required for the same results would be insensibly different. However, when it comes to more complex forms, these two processes become a matter of choice. Free forms of nature (empirical forms) and free forms that are geometrically based, as products of an algorithm, will choose its natural allies in terms of modeling tools. Thus, CAGD will be a more natural choice for modeling a human figure or figures of other living species, while parametric modeling will be a more logical choice for abstract free forms. Yet, there are also such natural forms that are closely related to mathematical formulas. The relationship of Fibonacci sequence with certain forms in botany and zoology is known, but these are not the only natural forms where procedural modeling can be applied in modeling. With implementation of generative approach, topographical surfaces, vegetation, or other natural forms can be successfully performed using procedural modeling.

Our intention was to get shapes that are created by continuous connection of the successive movements of an object, as a solidified animation. In other words, we search for the shapes created by "time imprinting" of the original feature into space, its arbitrary movements, and dynamic change of a position (i.e. 3D transformations). This is also a process that imitates the natural occurrence of similar forms of growth, arisen over time: from the growth of plants, through the formation of cave stalactites or underground canals, all the way to, for example, hair strands. We did not want to stay on the literal interpretation of these forms, but to extend the theme by using the same approach: a time imprint of the original shape in the form of a 3D figure.

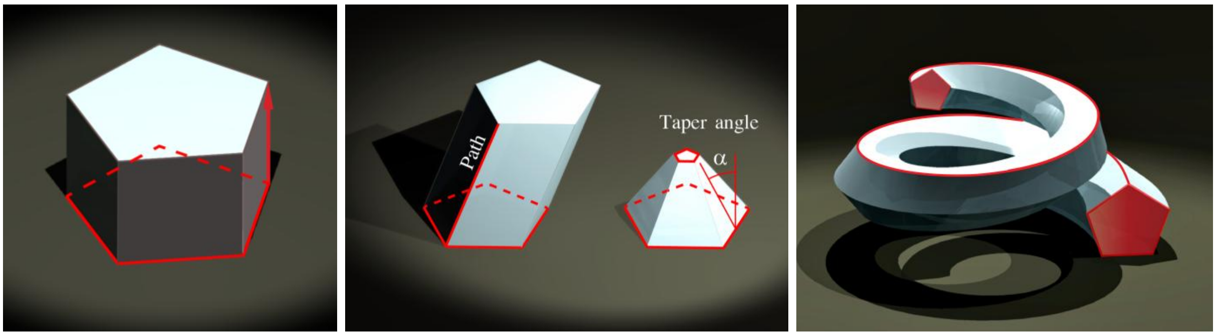
2. Time as a 3D Modeling Tool: Time Extrusion

The procedure itself is a variation of the sweeping scheme, whereby the starting object does not remain in a predictable position to the path, and the path also does not have to be predictable. The object moves along the path extruding its successive positions into one "mass", a unified solid object. In this way, if we would treat each of these successive positions as one "frame" of the animation, the shapes obtained in this way could be treated as a solidified animation, a frozen motion of the object. As motion is possible only with the time component, which also applies to growth, we have linked these two processes through the time component of generating shapes that remain as their consequences (imprints) in the space.
Time extrusion in this case means that the moving object extracts out all of its previous versions - positions, sizes, shapes, and transformations, leaving its complete history recorded in a single moment, in the form of a solid.

2.1. 2D figure time extrusion

When a profile (2D figure) in plane x-y is "extruded" by some of the 3D modeling procedures from the plane to the space (adding the third dimension), the 3D figure appears. This will be a surface, if the figure is an open linear, or a solid model, if it is a closed polygon. In this case, each edge of the profile will equally participate in the creation of a new solid's surface.
Let us try to replace the third dimension in the previous case with a time dimension. When a 2D profile performs a motion defined by a path, a 3D figure arises by linking its sequential positions.
Regularly, in CAGD modeling, if the path is a straight-line, it is a case of extrusion (Fig. 1 a and Fig. 1 b), and if it is a curvilinear path, it is sweep (Fig. 1 c). Since

sweep scheme is more general case of extrusion, it also allows a certain twist of the profile during the motion, which in fact means that the profile can rotate around the path at the same time. During this process, the profile can be scaled, whereby another spatial transformation is performed. These transformations are linear and thus predictable, because the position of the profile's plane along the path is known in each moment of the motion[1].



a) b) c)

Fig. 1: 2D profile extrusion (a, b) and sweep (c)

Therefore, what these standard procedures have in common is not only the predictability of the profile position at any given moment, but also the predictability of the surface that envelops the resulting body. On the contrary, if the motion of the profile along the path is unpredictable, randomly-generated with noise formula which means that the rotation angles and the tilt of the profile plane to the path line can be variable, the 3D object to be created in this way will have a more complex geometry, unpredictable edges and the surfaces, and will be closer to the natural free form structures. In this case, some of the edges of the initial profile may be "swallowed", within the volume of the new solid. It depends on the current position of the profile, i.e. on its position at the observed point of the path. Which of the edges will that be, which will take over their places and roles, remains a matter of occurrence, which brings a new variety of form and introduces a factor of contingency, an intervention of chance.

Creating 3D objects in this way is done according to the following: Let us imagine that we have an initial 2D object. It can be a simple one, like a regular polygon, or more complex, like a snow flake (Fig. 2).

Fig. 2: 2D profile of a snowflake

The form of the snow flake is taken as an example because it is also a result of growth [3] and the unpredictability of forming its shape is under the influence of several factors, from the crystal structure of the ice, to the influence of the external environment. Thus, it is a good example of a combination of geometric patterns and natural phenomena.

By taking a snow flake for an example (Fig. 2), we wanted to indicate the possibilities of triple-generational forms that could be obtained in this way: the unpredictability of the shape of the profile itself, the unpredictability of its transformations along the path of motion, and the unpredictability of the path itself.

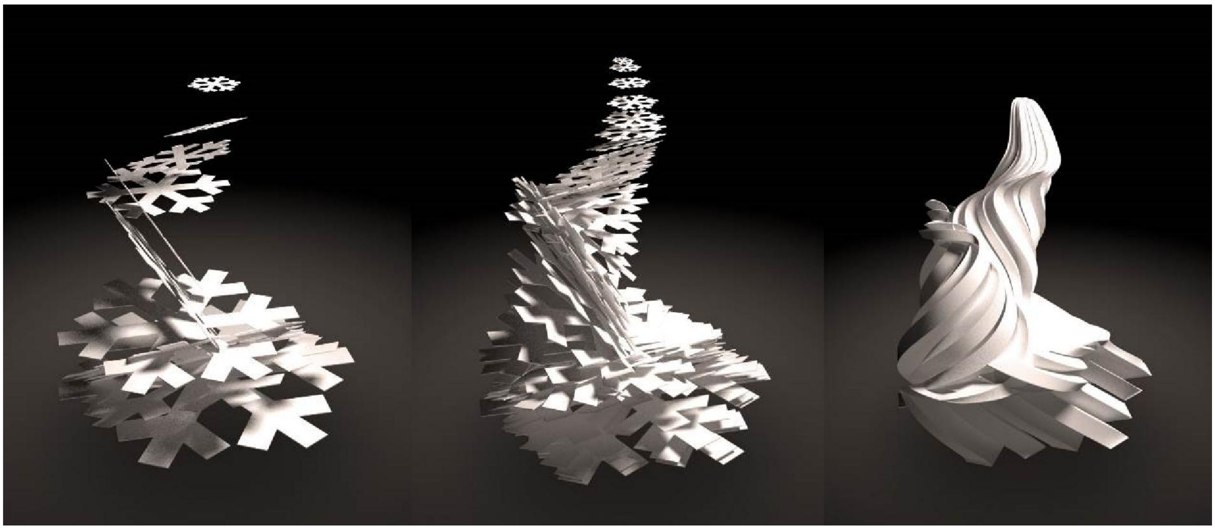


Fig. 3: Solidified motion of a snowflake, displayed by phases - frames

In this way, the solidified motion of snowflake (Fig. 3) in its form carries not only the recorded path of an arbitrarily chosen profile, but also manages to simulate an ephemeral process from the micro world perpetuated, to enlarge it and bring it from the everyday life to an artistic interpretation.

2.2. Forming the shape by motion of 2D figure

In the process of forming 3D shapes by changing its transformations, either they were random or given, the edges of the object should be considered. Every edge is, in fact, simple linear spline. Hence, we can also consider the object as a group of edges (splines).

The object moves through space and time. We can observe this movement as a movement recorded through a video, as a spatio-temporal set of transformations that are continuously integrated and make animation of the movement. Each frame extrudes each edge of the object. Polygons (the inner surfaces of the polygon) that make up the object are no longer important, so they might be even invisible. They are important for a static display of the object [1]. Accordingly, we come to what is particular for this modeling: as a standard, 2D objects are extruded, and the method presented allows and justifies an extrusion of 3D object as profiles, which then allows additional shaping and even lateral surfaces of the solid as new surprise factors in the final result.

3. Procedure Description

We used Blender3D with Cycle render for the visualization.
Random transformations of the objects have been generated with noise function applied to function curves. The phase parameter of the noise function (Fig. 4) has been used for fine tuning of transformations.

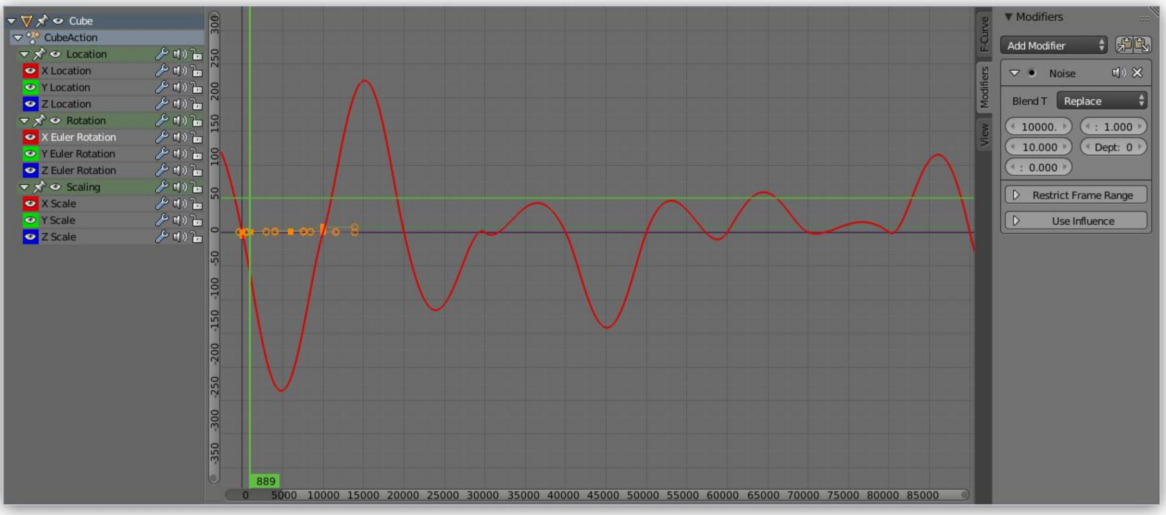


Fig. 4: an example of a finction curve used to rotate in Blender3D

DupliFrames tool with high number of duplicates has been used to duplicate objects along a transformation path.

If we extrude in time random positions of the profile along an arbitrary (random) path, practically countless possible positions of the profile are multiplied by yet another component of innumerable positioning possibilities. So, the actual shape will be the one of the possible cases which, in an elusive manner, connects certain positions between the random in one continual movement. This result gives an illusion of coordination between all of the previous randomities into a thoughtful sequence, which comes out of the frame of the author's idea (Fig. 5).

Fig. 5: a) The shape obtained by motion of a profile along a random path

3D figure time extrusion

Since in standardized 3D modeling procedures, extrusion capabilities of 3D profiles (already three-dimensional figures) are not specifically considered[2], we will notice some extra properties of such extrusion, examined from the geometric aspect.
By including a 3D figure in creating a new solid, the uncertainty of its shape increases for one more level, due to the unpredictability of the of the surface's outline, which the solid itself leaves behind as a trace of its movement.
3D figures can be defined by different geometric surfaces. Locally speaking, they can be, depending on Dupin's indicatrix [9] of the tangential planes, or. Gaussian curvature:

- parabolic (cylinder, cone), the tangential plane touches the surface by a straight line, Gaussian curvature equals zero
- elliptic (spheres, ellipsoids, torus ...), the tangential plane touches a point, the Gaussian curvature is positive
- hyperbolic (reversible hyperboloid, hyperbolic paraboloid ...), the tangential plane touches two lines, Gaussian curvature is negative.

Depending on the complexity of the 3D profile's surface itself, as well as on the complexity of the path, different and not always predictable results can be expected in the creation of the newly obtained solid's envelope surface.
Let us take a simple parabolic surface – cylinder, as an example (Fig. 6). Its motion along a path will give an envelope surface corresponding to the motion of a cylinder's directrix along the path. Such a surface can be: from 2D surface (plane) to more complex ruled surface. The axial plane of the cylinder remains perpendicular to the path, due to the base circle tangentiality.

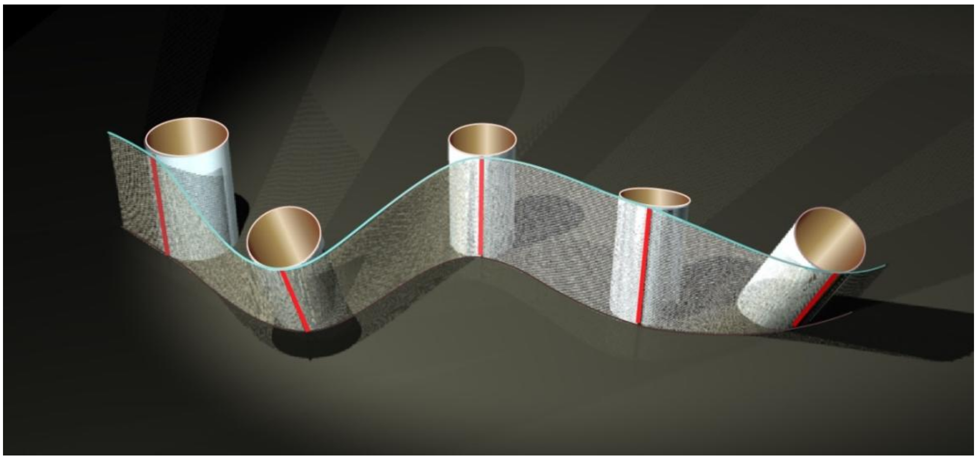
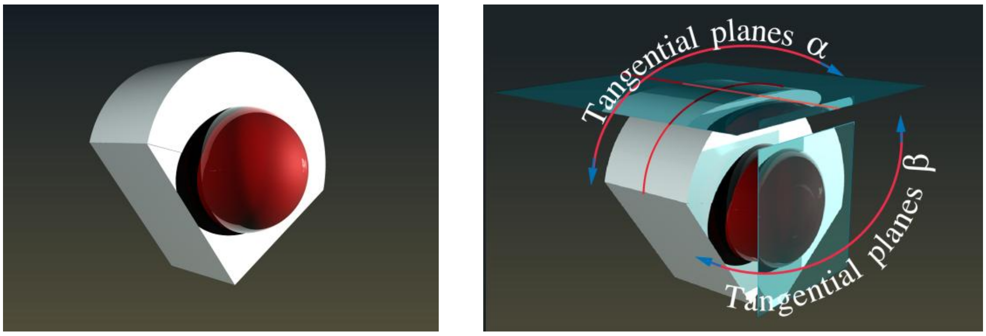


Fig. 6: The surface that arises an envelope swept surface of a cylinder

As another example, the motion of the sphere along a circular path will give the torus, corresponding to the motion of one of its great circles. Even the movement of the sphere along a more complex path will not provide notably different results, comparing to the motion of a circle. In these cases, the transition from the 2D to the 3D figure is not reflected on the final outcome of the obtained solid and its outline, because the surface normals stay perpendicular to the path.

But, if it is the case of a composite solid, as in Fig. 7, where there is a combination of cylinder, sphere and cube, then its movement along an arbitrary path, even be it just a translation (no other transformation applied), as in Fig. 8, already produces less predictive outcome concerning the surface that will be the result of its extrusion.



a) b)

Fig.7: a) an example of a 3D figure b) the surfaces of the figure that leave their imprint in space by time extrusion

We show an illustration of 24 translated positions of described composite 3D figure along the path in Fig. 8, in order to show that on certain sections of the trajectory, the different surfaces of the figure are visible, the ones that will form the final surface of the solid[3].

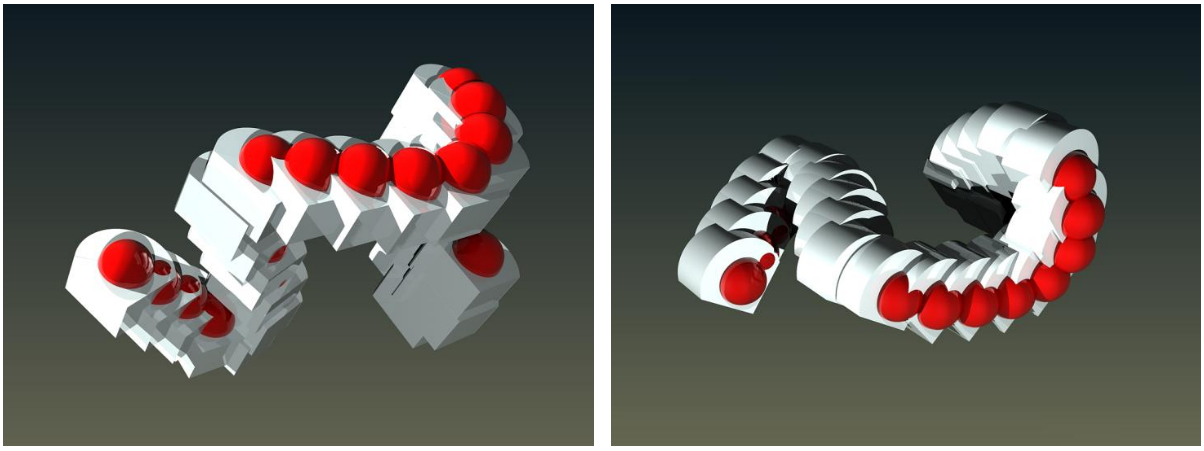


Fig. 8: The given 24 positions of the 3d figure during the motion along the path

If we add to the above the unpredictability of the 3D figure's position, due to the change of transformations while moving along the path, the effect of the unpredictability of the final result is further increased.

Thus the outlines, as well as the tangential plane to the surface of the so formed solid, are also of unpredictable position for each of the "frames". If the (random) rotation of the object is involved, and the 3D figure has curves, bumps, cavities, torsions etc., then the resulting surface gets an additional unforeseeable attribute, because what at one point was in the interior of the solid, "swallowed" by the mass of the other positions, may at some other point be found on the surface. In this way, the surface of so formed solid is not created only by the edges of the profile, but also by the curvature of the surfaces, the tangential planes of the figure itself, as the

envelope of the newly formed solid's surface.
For example: the 3D profile, during the simulation, can be rolled over the given surface, thereby modeling the resulting solid which perfectly fits the surface, and yet it is chaotic and spontaneous.

To sum up: when a 2D object is swept along the path, a 3D solid is created; when the 3D object is swept along the path, 3D solid is created again, because in our 3D space we can not physically present more dimensions, but the resulting 3D solid carries information about the 4D that was present while it was in motion.
Fig. 9 shows a solid formed by random 3D transformations of the cube that moves along the simplest - straight line path. The result is a 3D figure that emerged as a time imprint of such a movement of cube in space.
The random-case example could be an illustration of the solidified motion of the play dice while throwing it.

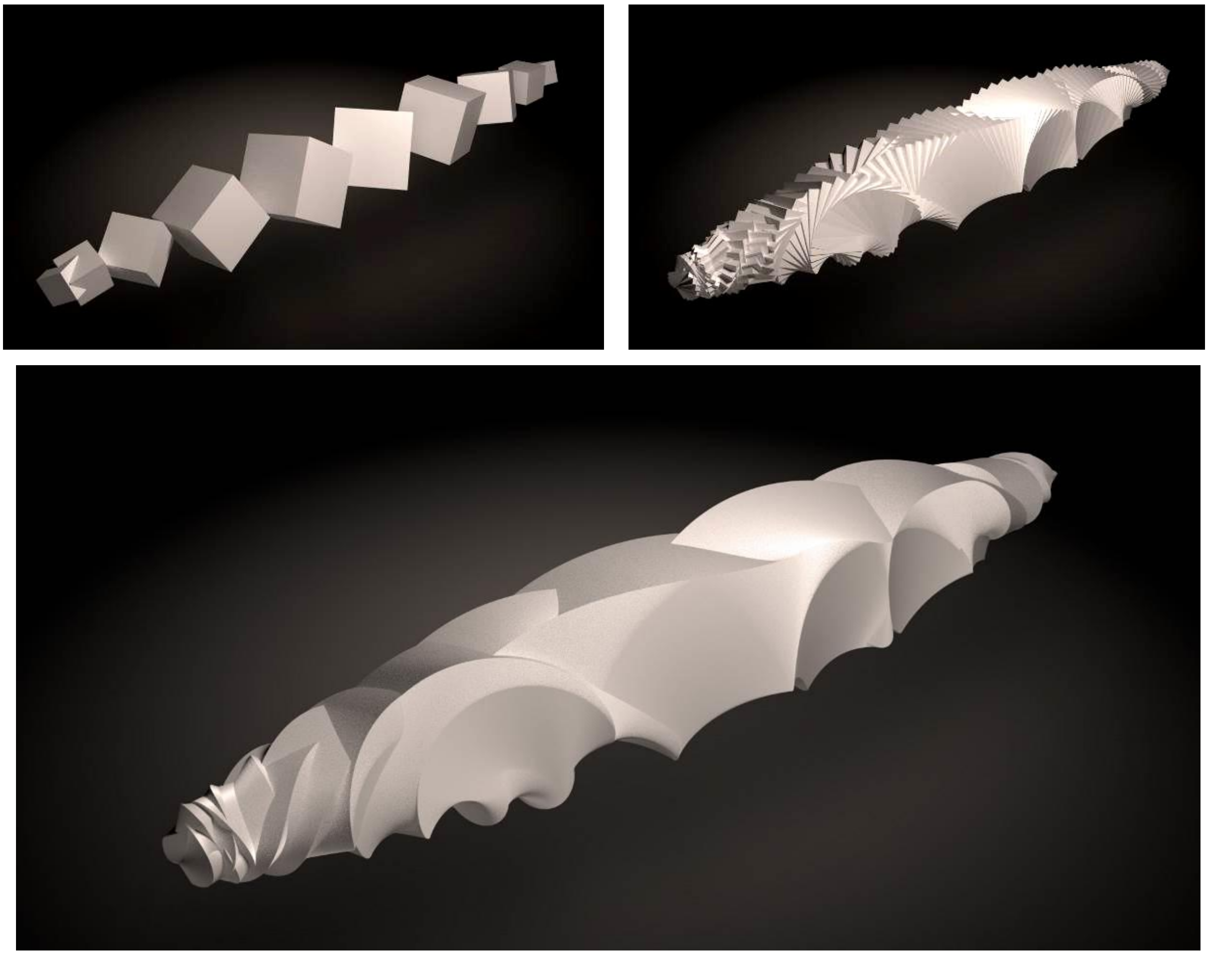


Fig. 9: examples of 3D object – cube time extruded linearly

4. Animation as a modeling tool

When we transfer the above considerations from theoretical to technical aspect, we may treat the animation of an object, which is by definition time-dependent, as a 3D modeling tool. Animation can be defined by key-frames which are describing

transformations, thus creating a continuity of movements and creating a spatial-temporal framework characteristic for this way of modeling.
If we have assumed that 3D solids are created by changing transformations in time, and that transformations involve changing positions of the solid (translation, rotation, scaling), such a motion of the solid can be associated with path animation. Path animation is just a variant of translation ("translate along a path") that allows us to visually define the path of the object. Path is actually a helper object and will not be displayed in the model, alike the path in 3D modeling tools which is also just an auxiliary object, not displayed in the final result.

Additional value of animation as a modeling tool lies in the fact that it is a creative process, and as such has expressiveness. It has its own language: acceleration and deceleration, interruptions and repetitions, squash and stretch (concepts introduced by Disney), inertia, forces that affect the object. In this way, transformations are complemented by deformations, the object experiences alterations over time, all of which are recorded in a solid form.

Animation can also be a spontaneous simulation of motion generated by the influence of force such as gravity, vortices, attractive and reactive fields, simulated winds, etc. Right then, the element of the occurrence takes effect, by turning modeling process into an experiment in which each result comes as a surprise.
The motion of the cube from Fig. 9 could now be complemented by changes in its successive shapes, when scale transformation would be randomly applied to its individual dimensions, not only to the overall solid. The result is the additional unpredictability of its final form (Fig. 10).

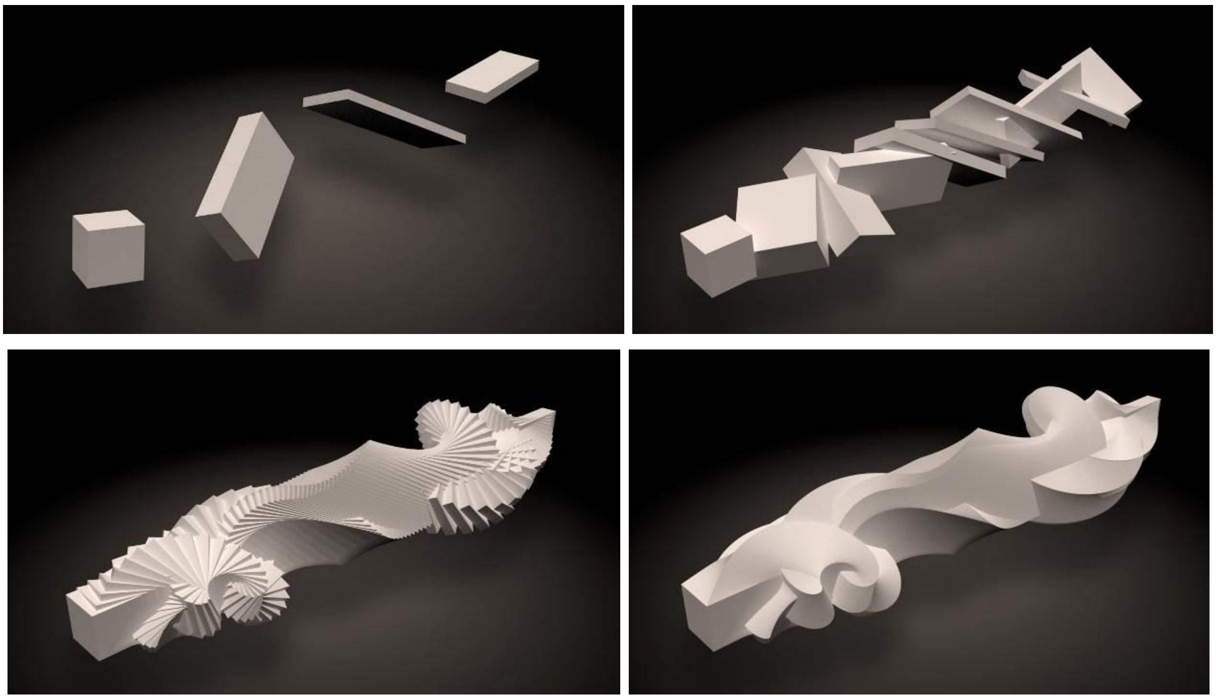


Fig. 10: Time extrusion of the cube randomly scaled by its individual dimensions

As a result of this process, we get a solid that is actually a three-dimensional projection of a four-dimensional space-time structure, its imprint in 3D space, using the time dimension.

5. Examples of complex forms generating using the time extrusion technique

Based on the aforementioned procedure, we can approach the experiment of generating forms by random motion of a complex 3D object (concave bipyramid CbP II-8 **Error! Reference source not found.**) and by a group of objects set on the assigned or random path, in order to compare the results and see clearly the differences in the "time imprint" of these forms in space.

The sequence of solid formation by random rolling of CbP II-8 along a path, as time extruded motion of the shape, we show in the Fig. 11.

Another example is given, showing a group of objects that move by random paths and transform dynamically (Fig. 12).

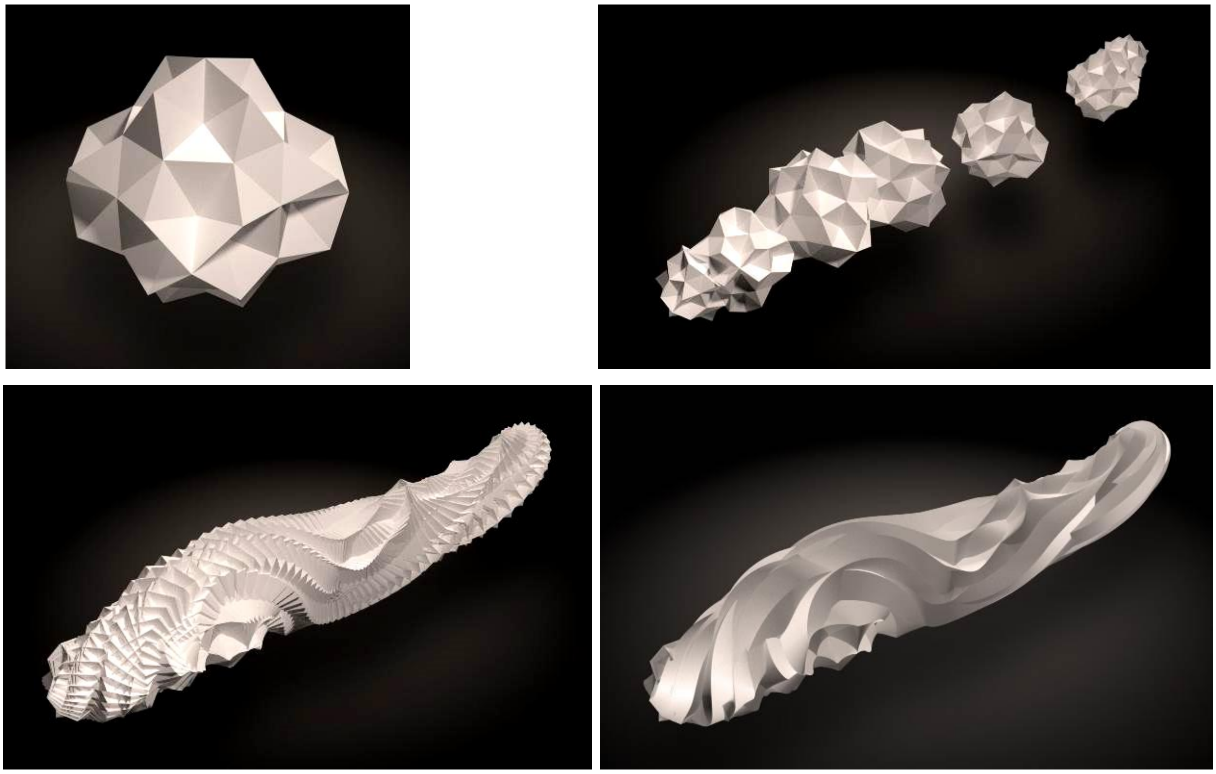


Fig. 11: 3D object –Concave bipyramid of the second sort (CbP II-8) time extruded

The space between the objects in the group allows each individual element to appear in its shape, without losing and disintegrating the edges within the solid's mass, making the starting figure unrecognizable. The composition of several elements adds an extra challenge in the interaction of the figures themselves: when and whether they will be interlaced, crossed, penetrated or bypassed, creating a fluid play of shapes struggling simultaneously for domination and harmony.

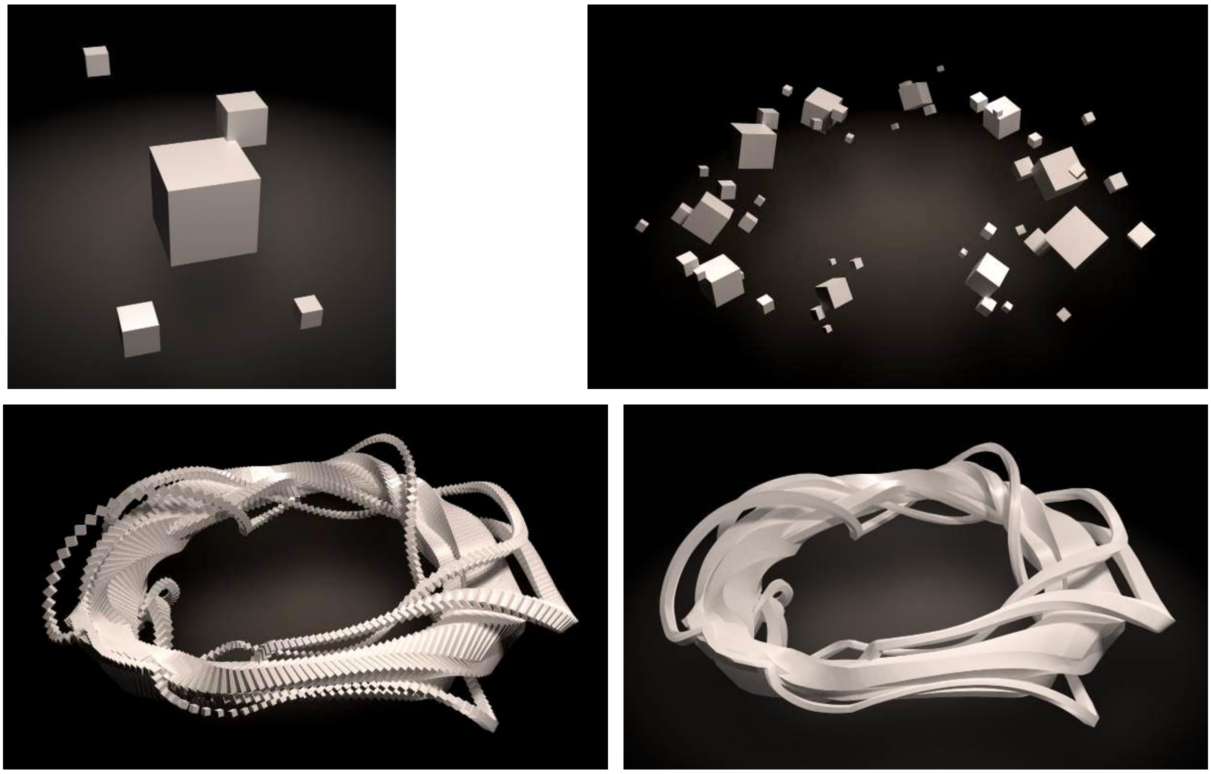


Fig. 12: example of group of 3D object time extrusion by a random closed path

The results we have obtained testify that the more complex initial forms will produce the even more complex outline of the outcoming surface of the solids. Although this was expected, the playfulness of the shapes, outlines, masses and volumes would always give an unexpected and surprising result, which we can not know before the end of the experiment.

6. The Prospects of Application

The forms obtained by time extrusion, due to their playful and vivid lines can be used as decorative elements or act as individual sculptures. They can also be used more widely. Such shapes are characterized by continuity, which makes them suitable for 3D print [6]. This feature greatly contributes to their applicability in different areas of arts and design. They can also be applied at certain time lapse simulations of natural, physical or mechanical phenomena, in science and engineering.

Let us mention just a few of the possible applications of these forms:

- In architecture: from constructive elements, such as pillars, to ornaments [4], elements of interior decoration, elements of landscape architecture (patterns of green or floral areas), urban mobiles and the like.
- In design: 3D modeling of natural forms, e.g. human hair, vegetation, to forms in digital graphic design, illustration, animation, etc.
- In applied art: jewelry, everyday items.
- In art / sculpting: sculptures, fountains.
- In science: as 3D simulations of natural processes.

Conclusion

Starting from the basic tools and procedures for 3D modeling, we transposed extrusion from the instant spatial operation to the motion in time. This motion provides freedom in the form of random movements of the profile itself, and also a randomly defined path. We examined the results of the motion of a 2D figure, and then raised the problem for one dimension and examined the time extrusion, a solid trace in space, left by 3D profile during its motion, i.e. the changes of its transformations. We concluded that such time extrusion of profiles can be equated with solidified animation of the profile itself. Animation as a creative process gives additional freedom and variety of transformations, deformations and re-shaping of the figures. Taking all these factors of unpredictability, coincidence and freedom of movement, we generated random animation in Blender 3D software and examined the formation of shapes in the described method. We used selected 2D and 3D profiles in the experiment. The forms we obtained as a result of this study, along with analogies with natural forms, carry an additional component of the human impact – an artistic one, but also go beyond artistic, providing surprising and boisterous forms with the sophistication of human influence. As such, they might find application in numerous fields of design, arts and science.

Notes

[1] In most commercial programs, this position is orthogonal by default, but it is also possible to specify a different angle between the path tangent and the plane of the profile at the given point.

[2] They are not yet included in standard procedures, although techniques have been considered in some recent research.

[3] In this paper, we do not provide an example of a solid obtained with a 3D figure with curved surfaces, because their polygonal modeling would take too much time to render. These forms can be modeled volumetrically, so this might be a subject of further research.

Acknowledgement:

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