Report on visit of professor Denis Zorin

Recent advancements in 3D printing technologies made possible to easily print arbitrarily complex shapes with relatively little effort. One of the main advantages of 3D printing techniques is that the cost of fabricating an object is not strictly related to the complexity of the object itself, instead is proportional to the amount of raw material used in the fabrication process.
This is a very relevant difference with respect to traditional industrial mass production techniques where the cost of producing an object is dependent of the complexity of the fabricated shape.

For this reasons 3D printing techniques allow us to create complex structures at arbitrarily fine scale. This characteristic can be exploited to create single-material microstructures whose mechanical behavior on a large scale is radically different from the properties of the used material. With this approach we can simulate the mechanical characteristics of an arbitrary material by using a single material 3D printer. The idea is to explore a wide set of possible topologies of patterns and characterize how it changes its mechanical properties in correspondence of a change in the geometric pattern.

Each microstructure is embedded in a cubical cell. We suppose to have an infinite tiling of this microstructures, then we can simulate this homogeneous material to understand its mechanical properties. Then in a second step we constructed a vocabulary of microstructures that can be used to tessellate a volume and distribute different material properties within the volume itself.

This approach has been demonstrated to be very effective, as shown by the results we already achieved in the paper “Elastic Textures for Additive Fabrication” we published on ACM Transaction on Graphics in 2015. The proposed technique is capable either to construct flexible objects or very stiff ones by keeping the overall weight under a certain threshold. Also this technique allows to smoothly change the material properties within the same object, i.e smoothly variate from something very stiff to something really flexible.

This unprecedented adaptivity in definition of the spatial distribution of the mechanical properties of an object open up to a wide range of new applications. Indeed we can built objects that are flexible only in particular locations or they can bend only along specific directions. This feature can be really useful if integrated within a medical application, for example may lead to the constructions of ad hoc prosthesis that allow certain movements and prevent some undesired ones.

Unfortunately the practical application of this technology is very limited because, given the basic assumption of the cubical tiling of the microstructure, it allows only to generate shapes composed by regularly assembled cubes and it doesn't allows to create the creation of arbitrarily shaped deformable objects. The idea we developed in the days during the time that professor Denis Zorin was at the lab consist into create a shell of the object and align several internal layers of microstructures with the shell. In this sense the external part of the printed object will appear as a solid object, however within its volume it will have the microstructure that will allows to obtain the desired deformation once an external force is applied.

This new approach pose several new challenges and issues that here we resume. We also tried to define some possible strategies to solve this problem based on some experiments we tried and knowledge of professor Zorin on Finite Element Analysis:

- Issue: *The shape of each cell can arbitrarily deviate from the ideal cube where the microstructure suppose to be embedded when we estimated its mechanical properties*. One possible way to solve this problem may be to encode the deformation of the cubical cell and parametrize this deformation. In this sense, the space of mechanical properties is not just function of the pattern and its geometrical properties but the deformation of the cell it is embedded. This may complicates a bit the overall analysis introducing additional degrees of freedom but it seems to be a reasonable way to solve this first practical issue

- Issue: *The shape of external boundary of the object (the shell) may significantly influence the mechanical behaviour of the object*. In this sense we must first estimate how much thin we can actually fabricate the external shell without break it. To this purposes we identified a set of experiments that allows us to understand the minimal thickness of the fabricated shell and how this shell deforms under external force. Notice that the deformation is also function of the curvature of the shell itself. We will maybe need some specific setup to capture the deformation of the printed shell in order to evaluate its mechanical behaviour and its local physical properties in function of the curvature and the thickness.

- Issue: *In case the external shell impact the overall deformation, we must be able to model this deformation within a FEM analysis framework*. One possibility may be to integrate the volumetric decomposition of the volume (subdivided in tetrahedral cells) with the external boundary that can be modeled by using bidimensional thin shell elements. We have analyzed all possible aspects about this integration in the Finite Element Framework we already have.