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Maxime Belperin, Sylvain Brandel, David Coeurjolly. Decoration of plastic objects using multi view-dependent textures. SMI, May 2012, College Station, United States. pp.17-26. hal-01120628

**HAL Id: hal-01120628**

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Submitted on 3 Mar 2015

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# Decoration of plastic objects using multi view-dependent textures

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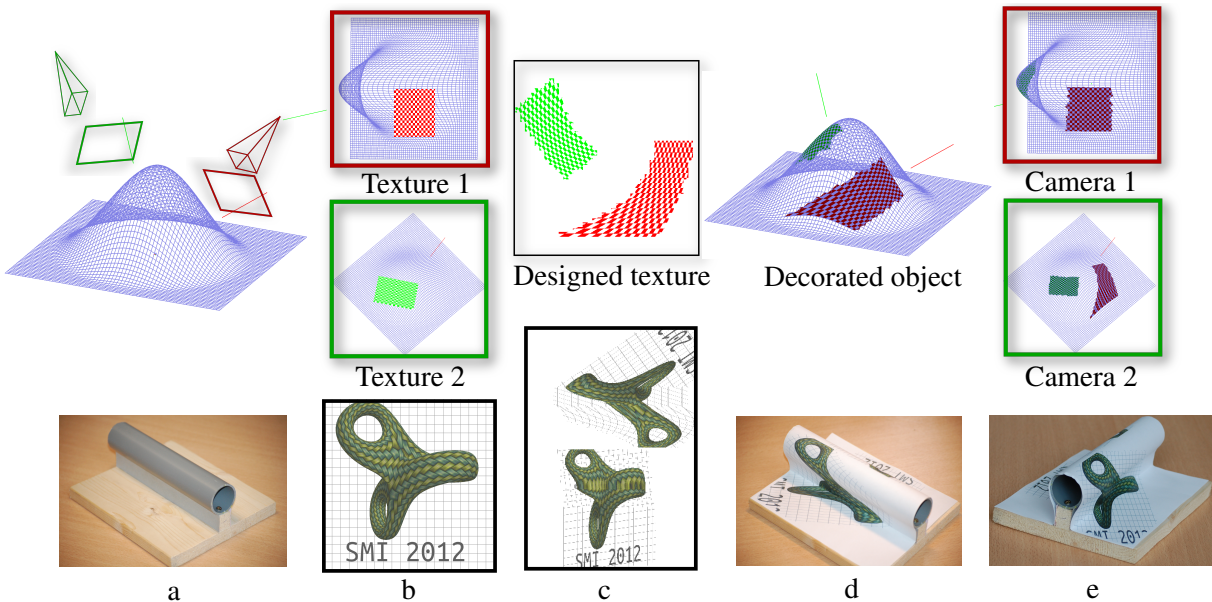
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## Abstract

This work takes place in the context of an industrial project, which aims to decorate 3D plastic objects using Insert Molding technology. The goal of our work is to compute the decoration of 3D virtual objects, using data coming from polymer film characterisation and mechanical simulation. To do this, we introduce a new method to bind texture mapping techniques to a physical process. In the general case of texture mapping, the surface (mesh) adapts the texture through the parameterization. In our context, the mesh comes from a physical distortion of an initial planar mesh, and our goal is to find the texture attached to the initial object, which gives the expected result after distortion. This texture combines information from several mapped images, which are visible from various views of the 3D objects. Moreover we want the texture mapping to be locally exact for all these views. To achieve this goal, a specific view-dependent parameterization is defined and the inverse transformation is applied to the mesh. Since the industrial project is not finished yet, we validate our process by texturing two simple real objects.

Project Page: <http://www710.univ-lyon1.fr/~sbrandel/en/projects/plastic-decoration/>



**Figure 1 :** Overall pipeline (top) and illustration on a real experiment (bottom). We consider an object and choose preferred view-points (a). We choose pictures to exactly match to these view-points (b). We compute one texture which contains all decorations (c). We then map this texture on the object. The quality of the final rendering depends of the view-point (d and e).

## 1 Introduction

This work takes place in a industrial process providing an automated method to design and decorate industrial 3D plastic objects. The packaging industry aims to improve the design of consumer products, particularly

in plastic or aluminum boxes. Plastics engineering industry takes into account the esthetic of injected objects like automobile parts or appliance equipments. Classical techniques consist of painting products after injection or thermoforming. For example, a pad can apply a small logo on a plane part, generally limited with monochrome ink. In Mold Labelling (IML) consists of transferring a small label at a precise location on the object. These techniques work fine for planar or quasi-planar surfaces, but are not adapted for non-developable surfaces. To avoid this limitation, the Insert Molding process follows two steps. first, a pre-printed polymer film is thermoformed. Then this deformed film is inserted in a mold into which the plastic is injected. The film is merged with the plastic during this injection. Figure 2 presents elements of this technique. The Insert Molding process provides great results with noisy textures such as wood or brushed aluminum, but with a limited object geometry (we call 2.5D objects). The ultimate goal of the project is to consider a wider class of 3D objects, including those obtained by injection processes.

Inside this ambitious project, we present here results on 3D shape simulation, with texture mapping of pre-deformed pictures. Even if the film deformation law is specific to both film material and the injection process, we suppose that the overall transformation is conformal (see below for details). Note that technical evidences confirm that this hypothesis is consistent with the industrial process we are interested in.



**Figure 2 :** *Industrial context. The hydraulic press and the kernel of the mold (a). The resulting object after injection (b). Thermoformage (c). Insert Molding (d).*

Another requirement is that we want the texture mapping to be locally exact for several specific views. In other words we are interested in a global parametrization of a unique texture composed of several view-dependent ones for which there is no visual distortion for given specific points of view: we design a specific texture and we want the printed object to visually match with the texture if we align the point of view accordingly, whatever the geometry of the object is.

Hence, we focused on the problem of view-dependent texture parameterization and inverse deformation to take into account the object geometry. Figure 1 highlights the overall pipeline. Our method is thus parameterized by an input mesh, a sequence of viewpoints and their associated local textures, and returns a single global texture to be used in the injection process. First, we explain how to combine local textures with the help of viewpoint based texture projections. Then, we create a planar uniformization of the mesh with the help of the discrete conformal theory (see below). Finally, we detail the global texture synthesis and preliminary objects validating the approach.

## 2 Background and Related Work

### 2.1 Techniques of decoration in plastic injection industry

Depending of the desired level of quality, several techniques allow plastic objects to be decorated. We can classify these techniques into two major classes: decoration with or without deformation.

In the first category, objects can easily be painted after injection. Tampography consists of putting ink

directly on the object surface with a stamp. In Mold Labelling consists in applying a preprinted label directly on the object surface. Both techniques are limited to planar or developable surfaces. Ink Transfer technology consists in positioning a preprinted film inside the mold. The mold is closed, and the plastic is injected. When the mold is open, the film is removed and the ink remains in the surface of the object.

Two main techniques allow decoration with deformation. Thermoforming is the most currently used in the industry. Extruded sheets or plates of polymer are heated to a temperature allowing deformation. A sheet is then positioned inside a mold (negative thermoforming) or on a mold (positive thermoforming). The sheet is deformed to the shape of the mold thanks to a mechanical pressure difference. The temperature depends of the polymer used, and is computed to obtain a flexible film, but hard enough not to flow. The desired object becomes rigid after cooling. The esthetic of the obtained object depends of the quality of the input film. Indeed, if the film has thickness irregularities, the heating of the film is irregular too, and the film is more deformed in the hotter areas. A homogeneous temperature is difficult to obtain, and differences of temperature induce tearing or heterogeneous deformations. The best results are obtained using ceramic or quartz infrared lamps or conduction of heated metallic element. The heating is influenced by the printed motif too. The type of the ink used and the color of the motif modify the capacity of heat absorption of the film.

Insert Molding is another way to decorate with deformation. This technology merges thermoforming and injection. A preprinted film, called an insert, is deformed using a thermoforming step. This insert is positioned inside an injection mold. The insert is then over molded with another polymer in the liquid state. Both polymers are merged during this step. For this reason the polymers used must belong to the same family. This technology provides great results, but some difficulties need to be solved, such as partial fusion of the insert caused by the temperature of the injected material, adherence of both polymers, and the maintaining of the insert in the mold.

Our overall industrial context led us to choose Insert Molding, thus needing film deformation. The most satisfactory computer graphics model corresponding to this physical deformation is conformal mapping, as proposed in [10].

## 2.2 Texture mapping

The problem of texture mapping and planar parametrization is very old since it was discussed as soon as man tried to map the entire Earth. Texture mapping has been studied for decades, and is implemented in all graphic processing pipelines [3, 5]. Mapping an image onto a 3D mesh requires prior calculation of texture coordinates for each vertex of the mesh. Planar parameterization techniques have been widely investigated for simple or regular objects, *e.g.* homeomorphic to a disc. In this context, many approaches can be described as energy minimization based processes: we define an energy function on the input mesh whose minimum corresponds to a deformation which makes the mesh planar [2, 4, 6–8, 10]. Approaches differ from the energy function design and the class of deformations considered. In the following, we use the discrete conformal framework proposed in [10]. Transformations within the conformal equivalence class of a mesh homeomorphic to a disc allow us to transform a 2D mapping of the input mesh with very interesting properties for texture mapping, namely angle and cross-ratio preservation.

In all these texture mapping processes, the main objective is to map a texture with a global 3D visual consistency. In our view-dependent process, we want the mapping to be exact (*i.e.* no distortions) for specific views. This view-dependency process is related to projective texture mapping introduced in [1, 9]. In these approaches, the idea is to use view-dependent information either to create shadows or lightning effects [9] or to construct intermediate views in an image based rendering process [1]. Our approach differs from these since we want construct a global parametrization of a unique texture from view-dependent textures.



### 3 Parameterization and Inverse Distortion

Our method is composed of several steps :

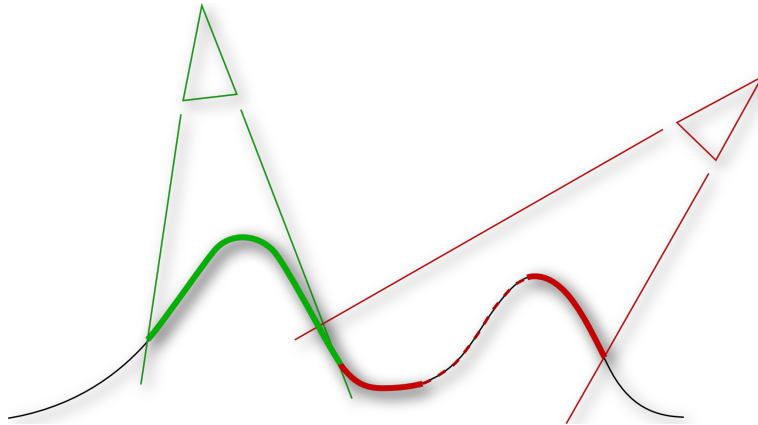
- We compute the 3D reconstruction of the mold
- Given a mesh, a sequence of view-points and their associated textures, we combine and map all the textures into the mesh,
- We compute the mesh inverse distortion,
- We compute the global texture map to print,
- We use Insert molding technology to decorate the plastic object.

Figure 1 highlights the overall pipeline of our method. We choose two views: a red and a green camera. In each projection coordinate system, we can then texture a part of the mesh, as we can see in the two colored boxes. As soon as all the textures and all the specific views have been processed, a conformal mapping is used in order to create the resulting texture. As a result, we can visualize the decorated object and the global appearance of the texture in each selected view beforehand.

#### 3.1 View-Dependent Texture Mapping

In this part, we want to associate texture elements with the mesh vertices. Since we expect an exact rendering of the texture on the surface, we adapt the view dependent approach as proposed in [9] to a global and unique texture synthesis. We take into account the surface geometry and do not map the texture on the mesh parts hidden from the selected view. In compliance with the industrial process, we prefer to keep only one connected component for a view and to map the texture onto it. Other choices can be made, such as a global mapping onto all visible triangles.

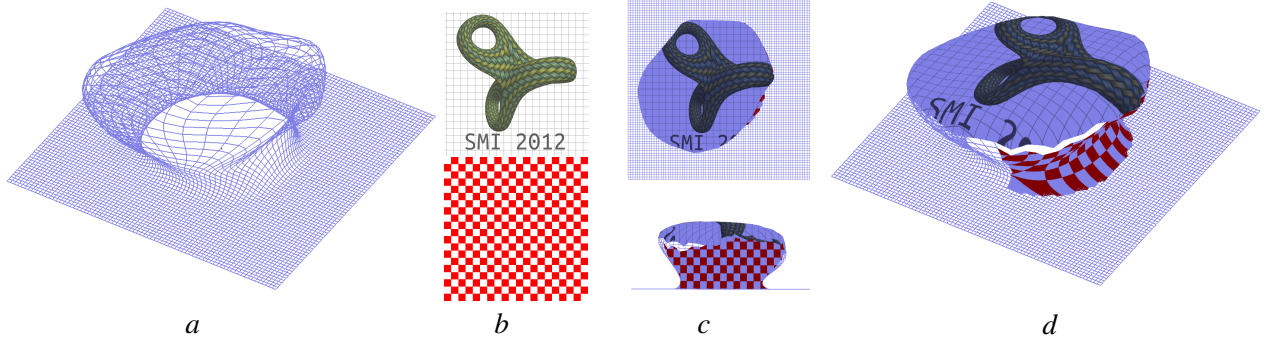
Several triangles can be visible from different view-points. We must make a choice: we can either blend the textures to obtain a new texture for these triangles, or choose one predominant view-point and favor it. We use the second way, in order to not decrease the visual result for all the view-points. This choice is caused by the fact that the 3D object design is impacted by the geometry, and so one view-point will be more significant for the designer. On the contrary, the first method makes all views non-exact because of blending. Therefore we prefer to get one complete and exact view-dependent texture mapping for the most significant geometry, and have a spatial limitation for the other textures.



**Figure 3 :** *Multiple view-dependent texture projection and visibility computation.*

When a texture zone is defined, we can either only map a texture onto this area and stop the process, or continue by choosing another view-point to map a new texture. We simply select one or more complementary view-points and we choose to separate the mappings between the multiple views of the object (Figure 3). We try to get an exact rendering for all the selected views, and we do not blend any textures together during the mapping. As a consequence the ordering of the view processing is significant: if a part of the mesh is already textured, this part cannot receive any texture coordinates.

According to the target geometry the number of view-points is usually limited by the injection process (Figure 4).



**Figure 4 :** *Multiple view-dependent texture mapping results: input mesh (a), original textures (b), the two good view-points (c) and real mapping from a generic view-point (d)*

### 3.2 Inverse Distortion

Many solutions exist to map a mesh  $M$  homeomorphic to a disk onto the plane. Since we expect the injection process to be conformal, we are looking for a conformal application from the mesh  $M$  onto a rectangular domain on  $\mathbb{R}^2$ . In the following, we use the theory of discrete conformal mappings introduced in [10] which can be sketched as follows: Given two meshes  $M$  and  $M'$  with the same topological structure (same abstract triangulation) but different geometries,  $M'$  is conformally equivalent to  $M$  if there exist an assignment  $u_i \in \mathbb{R}$  to each vertex  $v_i$  of  $M$  such that

$$l'_{ij} = e^{\frac{u_i + u_j}{2}} l_{ij} \quad (1)$$

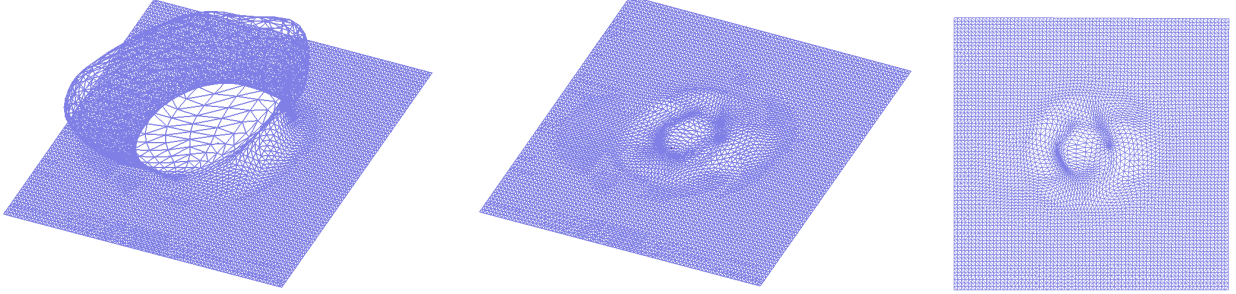
where  $l_{ij}$  (resp.  $l'_{ij}$ ) is the Euclidean length of the edge  $e_{ij}$  of  $M$  (resp.  $e'_{ij}$  of  $M'$ ), which has for endpoints  $v_i$  and  $v_j$ . Edge length can be linked to triangle internal angles  $\{\alpha_j\}$  by the law of cosine: let  $\theta_i$  be the sum of all internal angles of triangles adjacent to the vertex  $v_i$ . We can construct the following optimization problem: Given a target angle  $\hat{\theta}_i$  for each vertex, find the conformal coefficient  $u_i$  minimizing  $\theta_i - \hat{\theta}_i$ . In [10], the authors demonstrate that if a solution exists, it can be found as the unique minimizer of a convex energy function (with the constraint that  $\sum_{v_i} u_i = 0$  for scale invariance). Furthermore, they give an explicit formulation for both the energy function and its gradient.

In our context, given a mesh  $M$  homeomorphic to a disc, we can set the target angles such that  $\hat{\theta}_i = 2\pi$  for internal vertices,  $\hat{\theta}_i = \pi$  for vertices on the boundary of  $M$ , and  $\hat{\theta}_i = \frac{\pi}{2}$  for four boundary points. In other words, we are looking for an assignment  $u_i$  such that the mesh  $M$  can be conformally mapped to a rectangular domain on  $\mathbb{R}^2$ , which solves our inverse distortion computation problem. With this input, a unique minimizer exists and a simple gradient descent can be used to compute the conformal coefficients  $u_i$  (see Figure 5).

For the sake of simplicity, we suppose that our input mesh has four characteristic vertices on its boundary for which the target angle would be  $\frac{\pi}{2}$ . Once the coefficients  $u_i$  are obtained, the planar mesh  $M'$  can be

reconstructed using the same layout construction as in [10]. In other words, we maintain a one-to-one and onto mapping between the vertices of  $M$  and vertices of the planar mesh  $M'$ .

In the previous section, we have attached target texture coordinates to the vertices of  $M$ . Thanks to the conformal mapping, such texture coordinates are propagated to the planar mesh  $M'$ .



**Figure 5 :** *Mesh  $M$  and its conformal mapping  $M'$  onto the plane.*

### 3.3 Global Texture Creation

Once we have the planar mesh  $M'$ , we can construct a unique texture image, which gathers all the view-dependent texture information. Since such texture values are mapped onto the planar mesh  $M'$ , the unique texture  $T : [0, W] \times [0, H]$  is obtained by a bilinear interpolation. More precisely, we first map vertices of the bounding box of  $T$  to the four characteristic vertices on  $M'$  (those with internal angle equal to  $\frac{\pi}{2}$ ). Then, for each point  $p$  of  $T$ , we locate  $p$  in the triangulation  $M'$  and the color at  $p$  is given by the interpolation of the colors of the vertices of the triangles to which  $p$  belongs.

Finally, we can print the designed texture  $T$  on the plastic film to be used in the injection process. This plastic film must be placed and fixed on the mold very precisely, in order to guarantee a quality result. With this precaution, the process reliably produces good results.

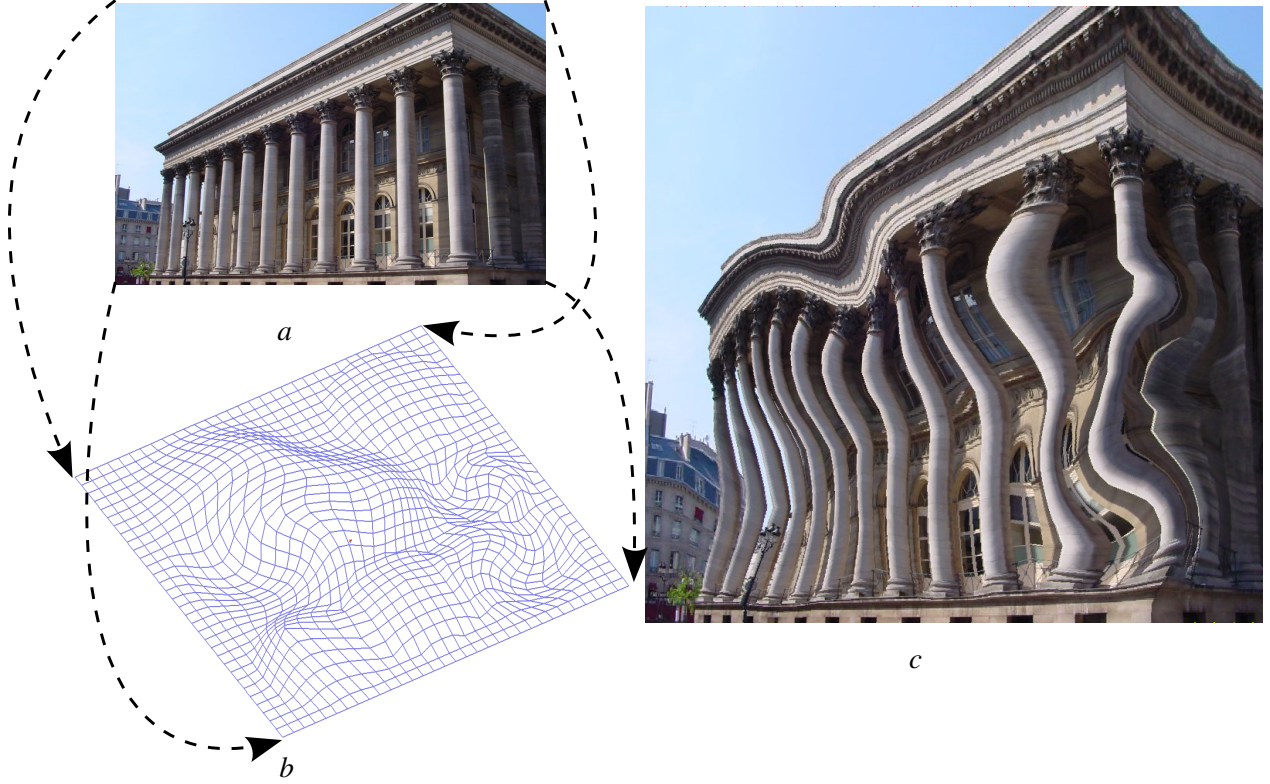
## 4 Results

The aim of this work was to demonstrate the overall computer graphics process; we do not yet have meshes acquired from a real plastic injection. Our inputs are synthetic regular meshes, artificially deformed, or meshes coming from a physical simulation. Figure 6 shows a deformed mesh, the original texture and the resulting texture. Note that Figures 1 and 5 also present results obtained by our technique.

In order to validate our system without industrial object construction, we applied our technique to an object which can be covered by a design printed on ordinary paper (Figure 7). This object is a half cylinder glued on a map. We modeled a mesh corresponding to this object, then we computed the view-dependent texture mapping and the inverse distortion to generate a deformed texture. We simply printed the resulting image with a laser printer on regular paper, and mapped this sheet onto our object. Since the paper is not deformable, we designed a developable object, instead of the industrial process, in which the texture is printed on a deformable film mapped onto a non-deformable object. In order to highlight the multi view texturing process, we use a second real object (Figure 8).

We present more results, videos, and high-resolution textures on our project page:

<http://www710.univ-lyon1.fr/~sbrandel/en/projects/plastic-decoration/>



**Figure 6 :** Regular mesh artificially deformed: original texture (a), input mesh (b) and distorted texture (c).

## 5 Conclusion and Future Work

We have presented in this paper a method to get exactly the expected visual result for a texture mapping from a viewpoint. This method is improved in order to take account of the mesh geometry and map several images onto the object. We have performed a multi view-dependent parameterization and the inverse distortion of 3D objects. Furthermore, we obtain one, and only one, image texture as a result. This image can be printed on the film for industrial process, or can be used with a uniform parameterization on the distorted mesh, to have the same visual result.

The first meshes used are homeomorphic to a disc and previously artificially deformed, or similar meshes from simulation. The main textures used are a chessboard and texts, to respectively visualize the distortion effects and the precision of the details.

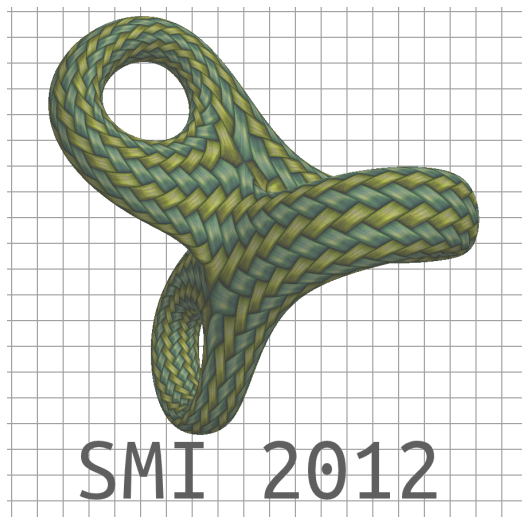
The choice of complementary views can be impacted by the geometry. When mesh parts are already visible from several views, the remaining points/faces can give guidelines, allowing us to choose the next viewpoint more efficiently. This help must not be restricted to give only one result, because the method can find only one optimal viewpoint, but other constraints, for instance from designers, may be more significant for the decoration of 3D objects.

The decoration of more complex objects requires transfer of images printed on several films, each of them applied to a limited area to take into account the mechanical constraints of the films (heat and tear resistance). The edge of the films may be not rectangular. Our work is to determine the mesh patches, in order to parameterize locally from one point of view.

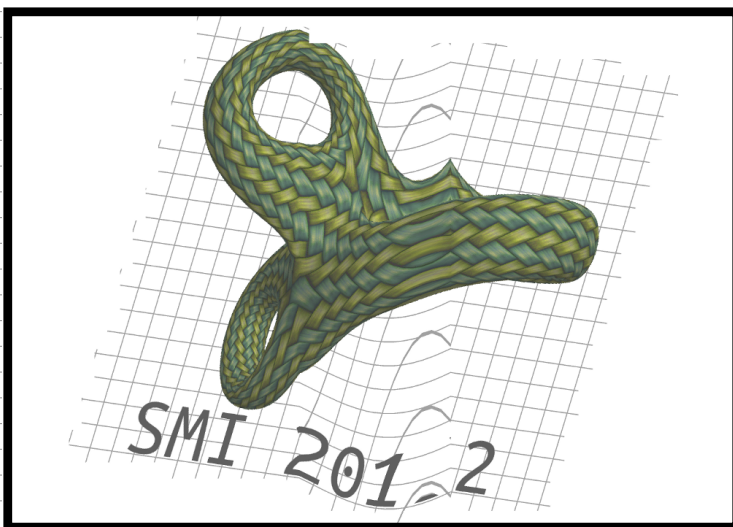
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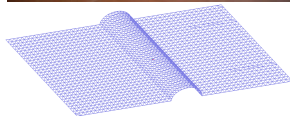




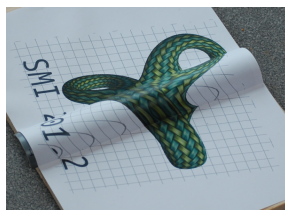
*a*



*c*



*b*



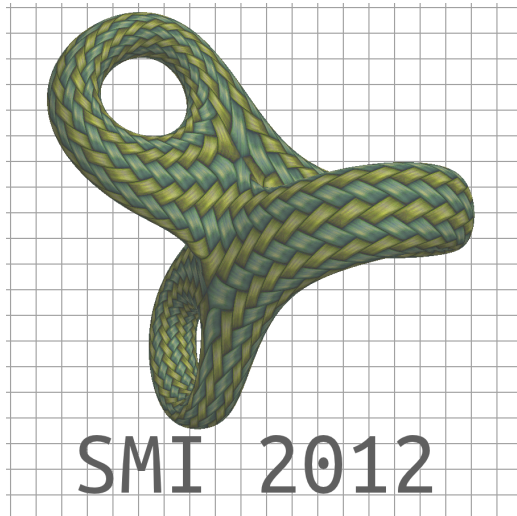
*d*



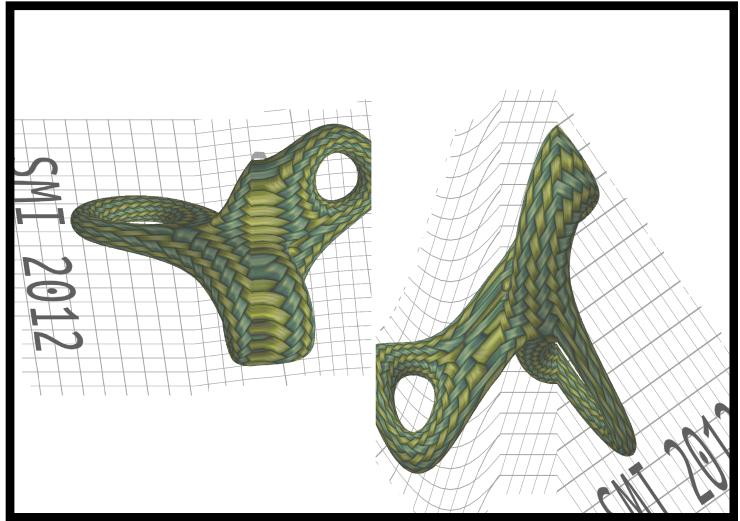
*e*

**Figure 7 :** Experimental illustration of our system with *one decoration* and *one view-point*: original texture (a), real object and its corresponding mesh (b), distorted texture (c) and real mapping from a generic view-point (d) and the chosen view-point (e).

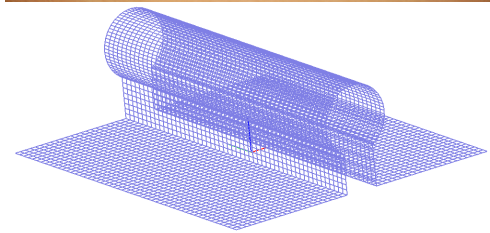
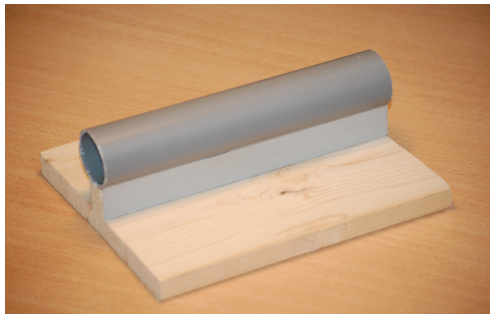




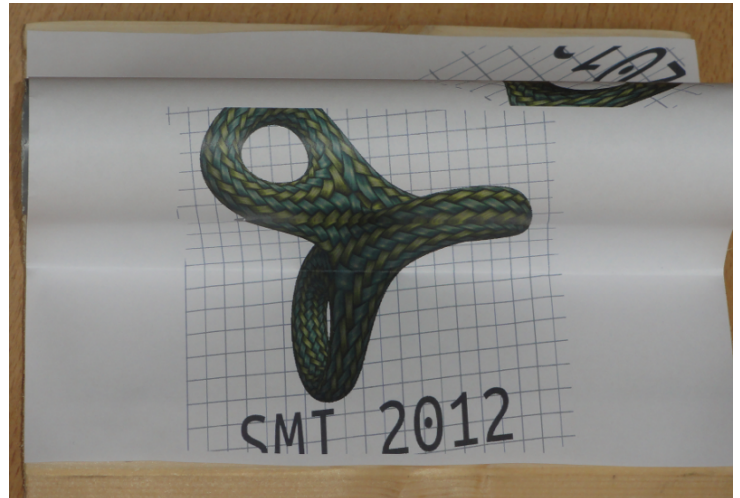
*a*



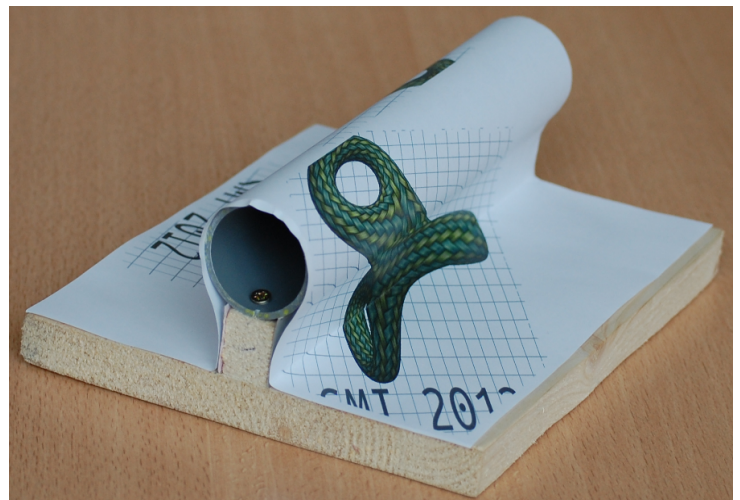
*c*



*b*



*d*



*e*

**Figure 8:** Experimental illustration of our system with *multi view texturing*: original texture (a), real object and its corresponding mesh (b), distorted texture (c) and real mapping from a generic view-point (d) and the two chosen view-points (e).