3D scanner characterisation for Open Design

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Abstract

The 3D laser scanning technology has been reached by more and more users in the last years, thanks to a new market of low cost devices, more affordable for simple, non-professional use. The educational use is one of such environments, and its didactics purposes gives the opportunity to test new technology from a variety of different point of views. 3D laser scanning, for example, is very promising in environments like Design university education, where the control of the shape of an object is one of the topics discussed in courses, and one of the main focuses of the product design profession. This paper describes the use of this technology in students and research lab, and its metrological characterization, especially on the relationship between performances and object optical characteristics (like gloss and color), object position and ambient lighting. It is to keep in mind that, in a student lab, geometry reverse acquisition is one of the activities done to understand products layout: the knowledge of influences of surrounding and material characteristics on scanner performances is a key factor to improve the performance when low cost scanner are involved. The characterization performed gave the opportunity to students to test how such devices work, the output reliability, which are the inherent issues and what kind of strategies should be introduced to enhance the scanning quality, indeed one of the main problems of these low cost devices.

The Working Environment

The lab involved in this research is the virtuaLAB - Politecnico di Torino Design Center, ITALY: it is a lab where students and researchers join to share their skills, in order to develop new strategies for industrial product design, environmental issues related to their production and new approaches to improve this Design and field. Open Source tools, open hardware, content production sharing and the connection with local FabLabs are some examples of the idea defining the activities developed in the lab [9].

One of the main goals is to focus the attention on people, their connection with other people and with the local area Design and production professionals, artisans and facilities.

The power of 3D printing is day by day spreading in everyday life and some new production approaches are growing and giving people new opportunities to get in touch with design production [1].

For this reasons virtuaLAB has adopted a low cost didactic/research strategy, not acquiring high-end technologies, preferring to test and use everyday devices, giving students and researchers the opportunity to create local activities related to the masses, thus choosing new development strategies for micro or even personal production assets.

The laboratory is equipped with five FDM 3D printers and one 3D scanner for reverse geometry acquisition: with these devices, easy to use, to modify and to re-release in different layouts, people working in the lab are able to test and develop different new product making approaches. Because of their studies, Design students have too much confidence on electronic devices (3D scanner, 3D printer and modeling software) and do not have the awareness to understand that the results these devices provide can be influenced by the object characteristics and environment. This study is a first step toward a more metrological approach on the performance knowledge of low cost 3D scanner, with the aim to define simple directions to improve performances and usability.

The device

The investigated scanner is a Makerbot Digitizer [2]: a very simple device, very easy to use and with software perfectly fitting for student's everyday use. Among its price range very few models are available.

This device has an electro-mechanical base, with a rotating platform (diameter 205 mm), two lasers and a webcam. The two laser stripes are used to minimize the undesired effects of occlusion.

The lasers technical specifications are:

- Wavelength: 650nm, nominal
- Total Laser Power (per laser): <3.5mW
- Number of Lasers: 2
- Laser Power for Classification: <300μ W
- Mode of Operation:CW (continuous wave)
- Beam Diameter: <5mm
- Divergence: 1 Radian x <5mRadian

Figure 1. The Makerbot Digitizer

The manufacturer does not provide any specification about the angular resolution of the rotating cradle, nor about the camera resolution. To improve the signal to noise ratio, a red filter is located in front of the camera. The two lasers produce a stripe on the object: during a full rotation of the platform are switched one at a time (to minimize occlusion), so to perform a full scan, two full rotations are needed and the total scanning time is about 9 minutes.

Manufacturer suggests performing a full system calibration every 20 scans or once every week, regardless of the scans number [3].

The calibration is a simple procedure with a reference object with a black and white grid to be scanned. It is suggested to put the reference object in the center of the platform, and perform a full scan with the object aligned along the two major axis.

It is also possible to verify the laser alignment: when both are on, their lines should overlap in the rotating cradle center. To reach this result, two different adjustment screws are available.

To begin a scan, the software asks only to choose the appearance of the object, in terms of perceived brightness: light, medium or dark appearance. It is suggested to choose this last set up when the object is particularly dark or difficult to scan. This is the only customizable set up available in the scanning procedure.

It is obvious that the object to scan should be placed in center of the platform.

Unfortunately, the manufacturer does not provide enough information about system performance or characteristic, and during tests we found the following additional limitations and problems:

1. 3D data acquired are saved only as mesh, not point clouds, it is therefore not possible to go back to the actual performance of the system as the software hides the raw scanning result, especially the number of acquired points that is directly correlated to the measurement accuracy. Unfortunately, this knowledge is a key point for a full metrological characterization of a 3D scanner, as clearly stated in literature [4]
2. scanning parameters, like, for example, point density, meshing algorithm or platform resolution, are unknown and not customizable
3. alignment procedure of the reference object is not easy, because no clear signs of cradle axis and center are present on the platform. This can be meaningful also during the scan when positioning non perfectly symmetrical objects
4. the laser alignment is almost impossible because the adjustment screws work step-by-step, not continuously, with very low accuracy
5. the low quality webcam with signal/noise filter
6. influences of the only customizable scanning set up about object brightness are unknown

The lack of manufacturer information about the system and the closed design as well, make difficult to assess the performance and to identify the best scanning set up and variables of influences, especially in a Design student's environment.

In optical scanners, as stated also in [5], the main problems arise from the following:

- Calibration procedure
- Accuracy related to scanner - surface distance
- Combination of multiple views
- Signal to noise ratio, due to ambient light but also to object surface specular reflection
- Occlusion effects
- Surface roughness

We recognize the statements of [6] according to which the technical specifications provided by the manufacturer are inconclusive and a customer procedure is needed, in order to assess performances. This is particularly true for the virtuaLAB contest, were no strong metrology performances requirements are involved or available.

Since the target of this research is to give students the ability to use this kind of scanner for simple didactics activities, we are interested in developing a very simple and reproducible procedure, in order to improve performances of affordable 3D scans for practicing with digital modeling, rendering and 3D printing for students.

In order to obtain this, the scan tests have been prepared, taking care of some features of the scanner, some of its limitations and of the working environment where the scanner is used.

In details, we tested the influences of the following:

- Environment lighting set up, considering the final scanning results only (because as stated before the system is completely closed and only final mesh results are provided)
- Customizable scanning parameters about object brightness (light, medium and dark set up)
- Achromatic object gloss
- Achromatic object position on the rotating cradle and distance from the laser-camera system
- Dimensional accuracy of achromatic object in the cradle
- Object gloss and color

Because the initial calibration plays a relevant role [5], we recognized that the identification of the platform center was weak, as well the definition of the alignment with camera and of reference object. Thus, the platform was equipped with a reference grid. The reference object for the calibration was improved in its center definition, enhancing the reference spin to center it. Unfortunately, the laser alignment cannot be improved, due to the laser adjustment system low accuracy.

Scanner performance evaluation

Achromatic objects: influence of lighting set up

As stated before, the scanner under investigation belongs to a laboratory, open to students, designed and organized with no specific care about internal arrangements regarding positions of scanner and 3D printing.

The laboratory is located in the new headquarters of the Politecnico Design Center, with high natural light contribution and tubular fluorescent light office luminaires.

About lighting set up, the manufacturer suggests only to avoid direct camera view of luminaires or windows; following this suggestion, the scanner was initially located in the open space of the lab and two different lighting set up were tested during the scan of a grey matt sphere: one using only natural light and the other using also artificial light.

It is obvious that a set with artificial light is preferable in order to ensure more reproducible conditions and the usage during the whole opening time of the lab.

Unfortunately, the artificial light provided by the fluorescent luminaires achieves the worst results with geometrical aberrations (Figure 2) and false geometries probably due to unwanted reflections and missed points.

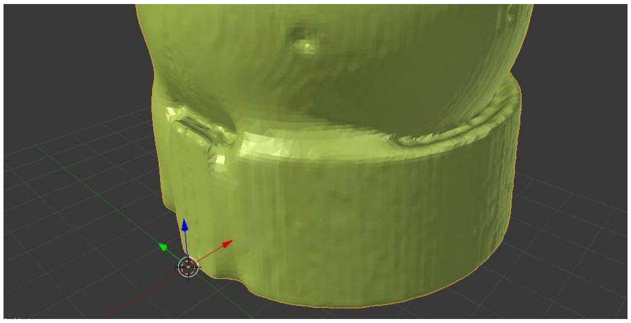

Figure 2. Geometry aberration

Achromatic objects: gloss influences

To test the influences of gloss of achromatic objects, a complex object was built, using the previous matt sphere and two smaller achromatic spheres, with two different gloss levels, connected by a stick. The object was placed on the center of the platform and tested with different light and scanning material set up.

The complex object is shown in Figure 3

The scans of the two spheres highlighted a new geometrical problem, the lack of geometry, (Figure 4), related to:

- Gloss of the samples;
- Lighting set-up;
- Laser alignment vs planarity and flatness of centered objects

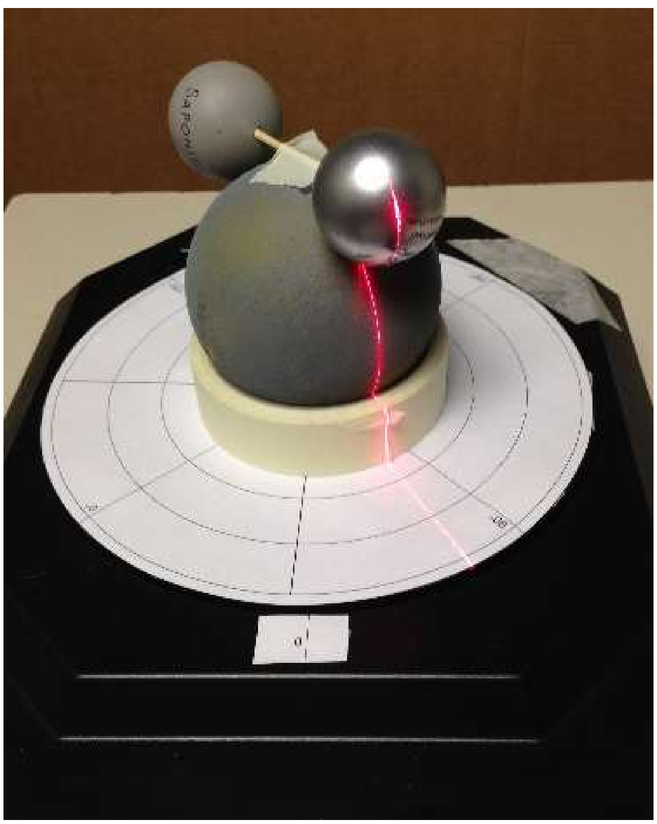

Figure 3... Complex sphere system to test achromatic gloss influences

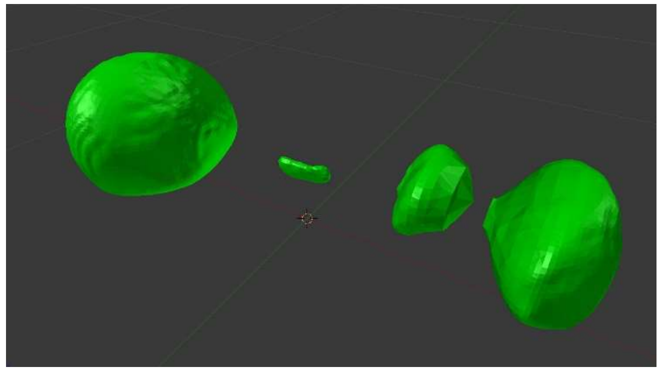

Figure 4. . Lack of geometry

Environment lighting set up and scanning parameters

The previously described tests highlighted the necessity to identify a position for the scanner station were the lighting set up can be easily controlled. The manufacturer suggests using additional lighting sources outside the camera field of view to overcome scanning difficulties and the office lighting clearly was not able to fulfill.

The initial arrangement of the scanner in the open space of virtuaLAB was not satisfactory, so the scanner was moved in the small photographic studio inside the lab, where there is quite no natural light contribution and the artificial light can be easily controlled thanks to two different diffusing photographic studio sources.

After relocating the scanner, the complex spheres objects was scanned again testing different light conditions. For each lighting set up a new calibration with the reference object was performed, and the only customizable parameters of the scanner, based on the perceived brightness of the sample, were tested too. These parameters are to be defined at the start of the scanning choosing between: "light material", "medium material" and "dark material"

The two photographic lighting sources were used in different lighting arrangement (Figure 5) and the three sphere system was scanned considering the three different option of material brightness.

The lighting set up providing the best results was the one with the diffuse lighting coming from the top. The problem of the missing geometry due to the planarity of a horizontal centered object in the center of rotation cannot be avoided, because it is an internal limitation of the scanning device, so the two spheres at different gloss were arranged vertically.

With this geometrical and lighting arrangement, the influences of scanning set up were tested versus the glossiness of the objects and scanning parameters.

The influence of scanning parameters in the manufacturer statements are related only to the brightness of material, and not to the glossiness. Although the tested spheres (light/mid grey) can be considered as light material, the best results were achieved with the "dark material" set up.

Figure 5. Different lighting setup, the best results are achieved with the set-up on the right

Achromatic objects: influence of position

Once defined the best scanning set up, the device was tested for the influences on the scanning results of the object position.

A grey achromatic matt sphere, 87,5 mm diameter, on a cylinder as a stand, was scanned in different position and with different set up (Figure 6).

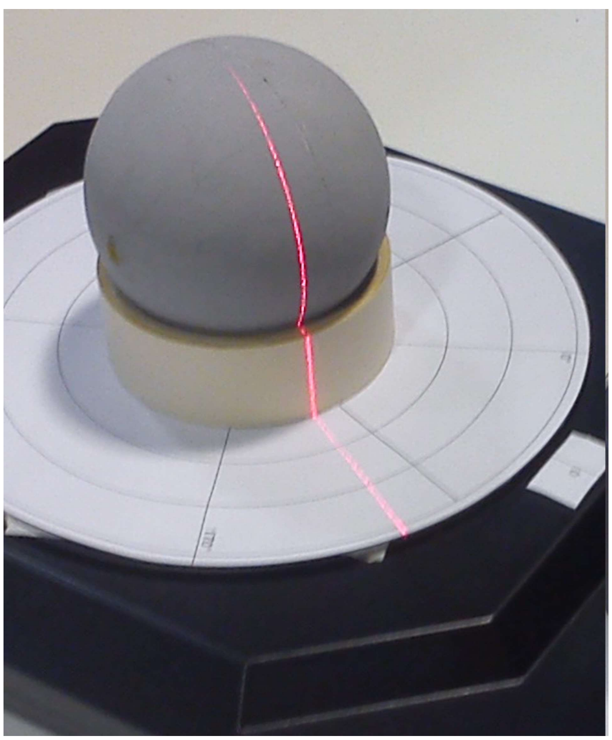

Figure 6. The grey achromatic matt sphere used to test the influences sample distance and position

To test the influences of object position to the center of rotation of the cradle, the matt achromatic sphere was scanned in five different positions: in the center of the cradle and displaced of the maximum allowed distance (i.e. the diameter of the cradle is 205 mm and objects must stay within) along each of the four main axis. The resulting meshes are compared each other translating the center of the 3D-model and calculating the geometrical subtraction and maximum discrepancies. A graphical result is shown in Figure 7.

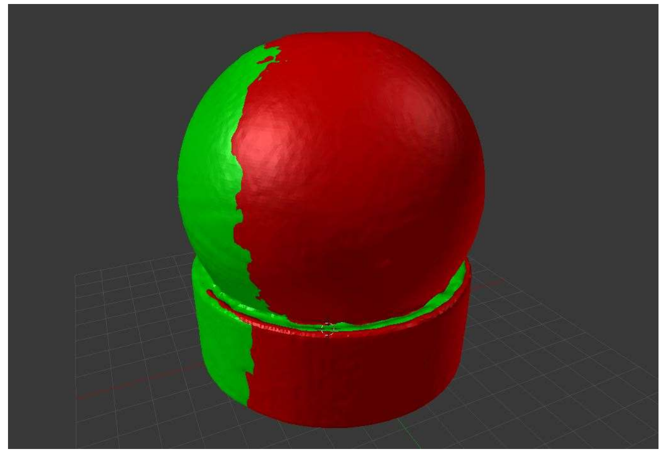

Figure 7... Geometry deformation of two different meshes of the same sample centered in the same point having been scanned in two different positions: one centered and one displaced along the x axis

The geometry deformation arrives always along the axis of displacements, but in opposite direction: the mesh of the same sphere displaced towards the positive versus of the x axis of the cradle, shows a deformation in the negative versus of the same axis with a larger dimension, while the dimension in the versus of the displacement is preserved. The maximum averaged (on the tested displacements) geometrical deformation of the sphere is 0,74 mm, toward the scanner camera, obtained for a displacement departed from the camera. The mean deformation along the other axis is 0,49 mm.

Dimensional accuracy

The previously described grey achromatic sphere, the easiest object to be scanned, was used to test the accuracy in the dimensional reconstruction of the 3D model. As shown in the previous paragraph, a displacement of the object from the center of rotation produce a deformation in the geometry in the direction opposite to the displacement. To avoid this, the sphere was centered on the cradle and the best set up (lighting and scan parameter) was used.

Five consecutive scans of the sphere were acquired without moving the sphere. To prove the influences of scanning parameter these scans were performed with "medium object" and "dark object" set up.

Then five more scans were acquired, but relocating the sphere in center of the cradle after each scan, only with "dark object" set up.

The diameters of the sphere were obtained from the 3D models along two perpendicular axis, and compared with the measurement of the diameter along the same axis on the real object.

It is clear that reproducibility of the scans in short time (standard deviation of measurements) is comparable to the artefact measurement uncertainty with low-level calipers, moreover the relocation introduces more variability in the measured values. Especially along the x-axis, were the previous test highlighted a geometrical deformation due to the displacement.

The results highlighted problems not in the data dispersion, but in the absolute value of the sphere diameter: an overestimation of about 3 mm is detected in all directions.

This clearly identifies a problem to be take in account, when reverse engineering is involved.

Object color and gloss

INRIM has several different colored flat object with three gloss levels: each of these samples were goniometrically characterized in a previous work [8], initially a single tile was scanned, but it was impossible to scan due to the previously mentioned problem with planar objects.

Once verified that the best object shape for scanning was the cylindrical one, we created a prism sample made by three planar faces, with different colors (White, Ged and Green) and different surface glossiness per face (figure 8).

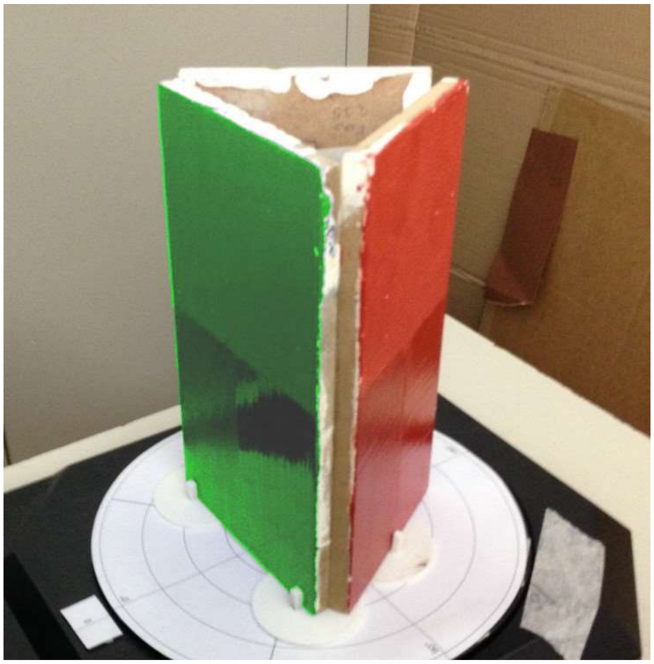

Figure 8. Prism sample

The prism sample was scanned using the previously mentioned optimal set up.

The first scans gave very interesting results from the red face, almost not recognized as planar by the scanner (figure 9), regardless of the glossiness of the surface, as a matter of fact, half-glossy and half matt. .

One of the most relevant issues, anyway, was about the behavior of the scanner with some combination of glossy, color and lighting conditions: an over-estimation arrives for the red sample, as shown in Figure 9.

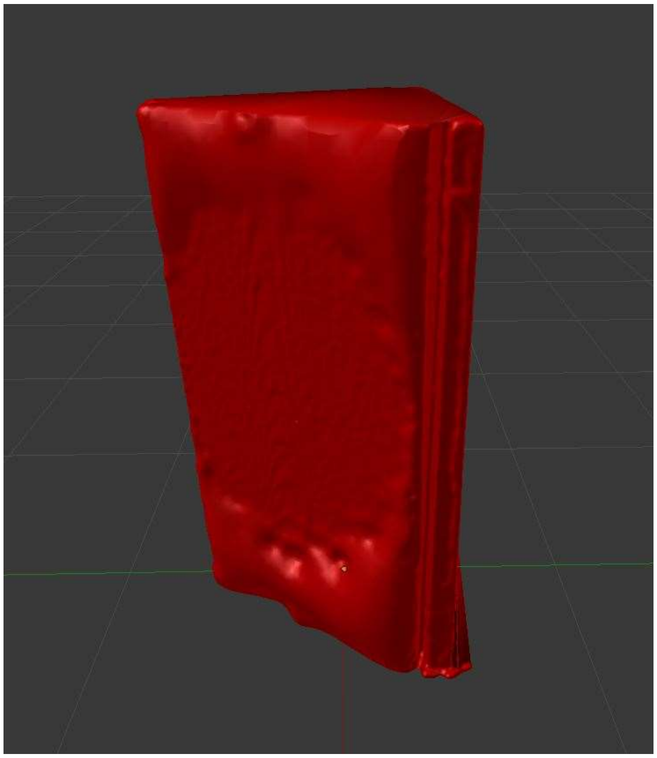

Figure 9. Non-planar face scan

Conclusions

The results of the tests and their analysis, allowed to identify a procedure to achieve the best possible results from this low-cost scanner.

The paper highlights that the performance limitations of this low-cost scanner are substantial; nevertheless it is possible to overcome some of them, and improve scanner performances.

First of all the scanner is now located in a dedicated area, where reproducible lighting conditions, satisfying the main requirements highlighted in the paper, are ensured. The center of rotation of the cradle is clearly identified and a radial reference system is available on the cradle surface. The reference object for calibration has been improved for reproducibility in position on the cradle, as well in solidity.

The objects to be scanned should be chosen also for their optical characteristics: the best object to be scanned should have a low or medium-low gloss level, a light grey or white color, a cylindrical symmetry and if sticks are present, these should be put vertically.

To achieve the best results the object should be put in the center of rotation of the cradle scanner and the “dark object” scanning set-up should be selected.

Starting from this preliminary research a dedicated procedure will be set-up.

It is important to remember that the scanner is used in a didactic Design environment, therefore the aforementioned set-up and procedures, even if not able to resolve all the issues, would be anyway useful: the not perfect resulting scans, would be enough affordable for students interested in the whole process of modeling, scanning, editing of 3D digital data. The Open Source approach that the lab is based on, in fact, uses a "learning by doing" methodology, putting students in condition to test a complete journey through every aspect of the Design process, from the scenario analysis, till the final product, walking all the steps in between, including those needing some expertise, developed while trying to solve bound problems.

Acknowledgments

The authors would like to thank the virtuaLAB staff for the effective work done, the support and the patience: the technical manager, Alessandro Dentis, and the fellow students, Marco Cataffo, Gabriele Del Vecchio, Umberto Gnocchi, Danilo Perozzi and Francesco Turina.

References

[1] F. Valpreda, "3D Printing Awareness, the future of making things", in Measuring, Modeling, and Reproducing Material Appearance, San Francisco, California, Vol 9398, p.93980X-1 – 93980X-14

[2] https://store.makerbot.com/digitizer

[3] https://mindtouch.makerbot.com/@api/deki/files/91/MakerBotDigitizer_UserManual.pdf

[4] B. Ramos Barbero, E. Santos Ureta, "Comparative study of digitalization techniques and their accuracy", Computer aided design, Vol 43, p.188-206, 2011

[5] T. Varady, RR Martin, J Cost, "Reverse engineering of geometric models- an introduction", Computer aided design, vol. 40, n.7, p. 812-827, 1997

[6] E. Vezzetti, "Computer aided inspection: design of customer-oriented benchmark for non contact 3D scanner evaluation", The int. J. of advanced manufacturing tech, vol. 43, p.1157-1166, 2009

[7] N. Vukasinovic, J. Mozina, J.Duhovnik, "Correlation between incident angles, measurement distance, object colour and the number of acquired point at CNC laser scanning", J of Mechanical Engineering, Vol. 58, N. 1, p 23-28, 2012

[8] P. Iacomussi, M. Radis, G. Rossi, "Goniometric and colorimetric properties of paints and varnish", Proc. IS&T Measuring, Modeling, and Reproducing Material Appearance, San Francisco, California, 2015

[9] C. Anderson, "Makers: The New Industrial Revolution", Crown Business, 2014

[10] http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/history

[11] P. N. Stearns, "The Industrial Revolution in World History", Westview Press, 2012

[12] B. Sterling, "Shaping Things" United States, MIT Press, 2005

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