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A new method for printer calibration and contour accuracy manufacturing with 3D-print technology

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A new method for printer calibration and contour accuracy manufacturing with 3D-print technology

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Abstract

Purpose – This paper aims to verify a new method for accurate part manufacturing using a 3D printer. In particular, the direction and position dependence of the printed results are to be verified within the building area. The results of the accomplished experiments are to be used for the computation of new printer adjustments.

Design/methodology/approach – Test cubes with a defined edge length were printed and measured afterwards. The test cubes were distributed thereby either over the entire building area or only for a small part of the building area. Next, the test cubes were measured and the differences between measured and desired values were used for adjustment of the printer parameter settings. Therefore, the "bleed compensation" settings were used.

Findings – The deviations depended strongly on the position in the building area of the printer. In dependence of the position and orientation, different deviations in the three dimensions of the printer coordinate system resulted. By a calibration of the printer parameters for a reduced part of the processed area, the print accuracy could be strongly increased. Afterward, the calibration the deviations could be reduced from 0.4 mm ± 0.2 mm to under 0.04 mm ± 0.03 mm.

Originality/value – The work shows the position and direction dependency of the 3D-printer manufacturing accuracy. Furthermore, a calibration procedure for bleed compensation calibration is presented.

Keywords Calibration, Accuracy, Printers

Paper type Research paper

Introduction

Rapid prototyping systems like 3D-printers are effective tools for quick product development (Gebhardt, 2000). Over the last few years, 3D-printer technology has made significant contributions regarding print rates and print cost in rapid prototyping procedures (Wohlers, 2005). The increasing choice of available materials and the numerous finishing processes available for the produced parts, greatly increases the range of the application areas for 3D-printers (Dimitrov *et al.*, 2006a, b).

For some applications it is important to keep the printed output as close as possible to the 3D computer model. For example, a close fit between produced parts or definite models of anatomic structures. The goal here is to print models with a high-contouring accuracy. Parameters like the location or the adjustment of the part should not affect the result. For this reason a high reproducibility is necessary. The authors wanted to approach this aim by a calibration of the software settings. Therefore, defined cubes were printed and measured in order to adjust the printing parameters of the system.

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A further advantage of 3D-printers, compared to other rapid prototyping systems, is the ability to produce coloured models (Gibson ands Ming, 2001).

The 3D print process

The 3D print process produces workpieces in layers. The principle of 3D-print is to distribute or print a liquid binder onto a loose plaster or cellulose powder bed. The print process is based on the ink jet technology. A local solidification of the powder takes place. Thus, elements of one layer are generated and combined with the subjacent layer. Unused powder remains in the work area and supports the model. The models must be imbued after the print process with a resin, otherwise they are not mechanically stable (Gebhardt, 2000). The principle of printing in layers is shown in Figure 1(a).

The main components of a 3D-printer are: feed piston with powder reservoir, print piston, roller and the print heads. To print one layer, the following steps are implemented:

1. The roller and the print head move from left to right. The roller turns in an opposite to the direction of moving. Thus, spreading a thin powder layer over the build piston (Figure 1(b)).
2. The roller and the print heads move from right to the left. The actual layer is printed by the print heads (Figure 1(c)).

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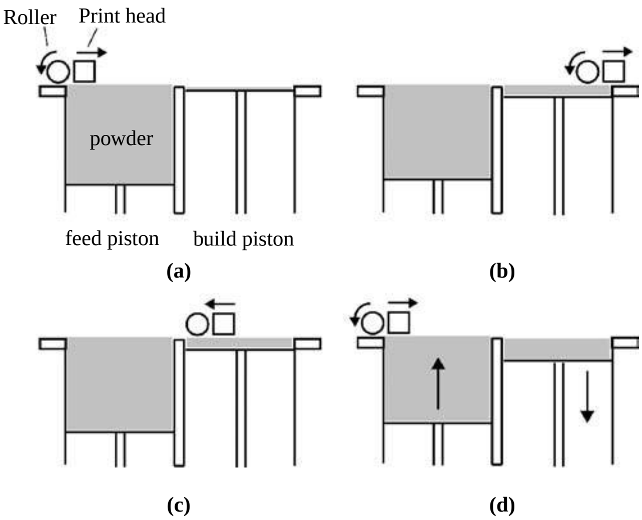
Figure 1 Representation of the main components of the 3D printer and the printer operation principle



Notes: (a) The most important components of the 3D-printer: roller, print head, feed piston and build piston; (b) the rotary roller drives from left to the right and carries powders into the building area; (c) the print head drives from right to the left and prints a layer; (d) the feed piston will be elevated, the build piston lowered

3 The feed piston is elevated and the build piston is lowered slightly (Figure 1(d)).

An important point with the manufacturing of models is the achievable accuracy. The accuracy requirements, for interlocking parts (Dimitrov *et al.*, 2006a, b) or accurate anatomical models (Stopp *et al.*, 2007) lie within a range of a tenth of a millimeter.

From the literature it is well known that the accuracy of the 3D-printer is affected by different factors. These factors are (Dimitrov *et al.*, 2006a, b):

- material used;
- nominal dimensions;
- workpiece orientation within the 3D printer;
- geometric features and their topology, e.g. open or closed contours;
- wall thickness – shell, solid;
- post treatment procedures; and
- binding agent.

The accuracy of process parameters of 3D printers was already examined using a special jig and a workpiece part with radii (Dimitrov *et al.*, 2006a, b). Further investigations were carried out regarding binder consumption and print rate (Yao and Tseng, 2002). Also, the z-height of the parts in three different positions in the building area was looked at.

For the comparison of different rapid prototyping systems, different gauges were developed (Dimitrov *et al.*, 2006a, b; Mahesh *et al.*, 2004). These however, did not account for the position dependent accuracy inside the build piston area.

The following section examines the suitability of 3D-printers for manufacturing parts with accuracy requirements of under 0.1 mm. In particular, the possibility of the calibration of the printer was examined.

Bleed compensation

For orientation dependent printer parameter settings, the "bleed compensation" of the printer software is used. When using the standard parameter settings, contours will be inaccurate (Figure 2(a)). This makes the printed part too thick. The degree to which the part becomes too thick depends on the orientation in the building area. The printer software offers the possibility to set the parameters for each direction separately. With accurate settings the contour of the part can be kept within limits (Figure 2(b)).

Material and methods

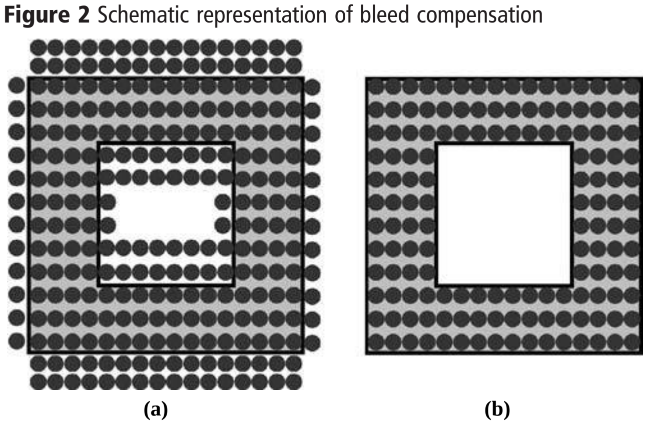
In preliminary tests it was observed that the size of printed parts did not correspond accurately to the data records. The deviations were between 0.3 and 0.4 mm. It was also realized that the errors were direction dependent. Preliminary tests seem to suggest that the errors were direction dependent.

Two experiments were conducted. Cubes with a defined edge length of 10 mm were printed. The purpose of the first experiment was to show how strongly edge lengths of the printed cubes deviated from the defined edge lengths. Special attention was paid to position and direction dependency. On the basis of the determined data a calibration of the printer parameters was made. With the calibrated printer parameters, more cubes were printed and examined.

The second experiment explored the dependency of a small section of the workpiece on position and direction. On the basis of the obtained values, a further calibration of the printer parameters for the reduced building area was made. The results were then compared with the results from the experiment over the entire building area.

The experiments used the printer model *Spectrum Z510* (company Z corporation) and the plaster powder *ZP130*. The printed cubes were measured with a caliper gauge. The measuring tolerance of the caliper gauge was given as 0.02 mm, according to the manufacturer. Subsequently, the cubes were treated with the infiltration material *PX100* and measured again.

Figure 2 Schematic representation of bleed compensation



Notes: (a) Without bleed compensation binder drops were printed beyond the structure borders; How many drops were printed beyond the structure border is direction dependent; (b) with bleed compensation: the binder drops are not printed beyond the structure borders

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Experiment 1a: verification of the direction dependency of the deviations in the entire building area of the printer

To verify the results of the preliminary tests, test cubes were placed over the entire printable area of the printer and measured afterwards, in order to determine whether the location and orientation of the parts in the workspace affected the printed results. The building area and the coordinate system of the building area are shown in Figure 3.

About 100 cubes were lined up in ten rows along the y-axis, with ten cubes each. The rows, like the cubes, were evenly distributed over the building area (Figure 4). The print was done with the standard parameter settings for the powder. The printer was allowed to reach its working temperature before the print.

Experiment 1b: calibration of the printer parameter setting for the entire work area

The values determined in experiment 1 showed direction dependent deviations from the given geometry. The values were used for the adjustment of the binder settings. The half of the mean deviations of the edge lengths $\bar{m}$ for each of the three directions in space were used as binder compensation d_x in the settings of the printer. These settings were stored as new powder settings:

$$d_x = \frac{\overline{m_x} - 10.0}{2} \tag{1}$$

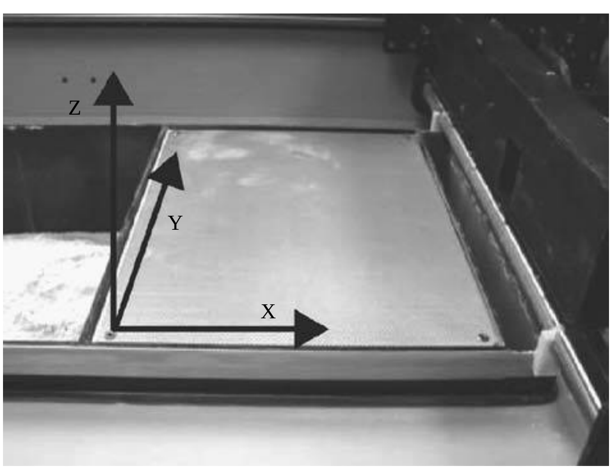
The established bleed compensation settings are shown in Table I.

About 15 cubes were lined up to three cubes each in five rows along the y-axis. The rows and the cubes were evenly distributed in the center of the workspace (Figure 5). The cubes were measured after the print.

Experiment 2a: verification of the deviations for a reduced building area

The results from Experiment 1a "Verification of the direction dependency of the deviations in the entire building area of the printer" lead us to assume that the dispersion of the edge lengths of the cubes are smaller on a reduced scale. In order to verify this assumption, 15 cubes in the center of the workspace were printed and measured. They were lined up to three cubes each in five rows along the y-axis. The cubes were placed in the center of the work area (Figure 5).

Figure 3 Workspace of the 3D printer with coordinate system



Note: The feed piston is seen on the left side, the roller on the right

Figure 4 Positioning of $N = 100$ cubes in the entire workspace of the 3D-printer

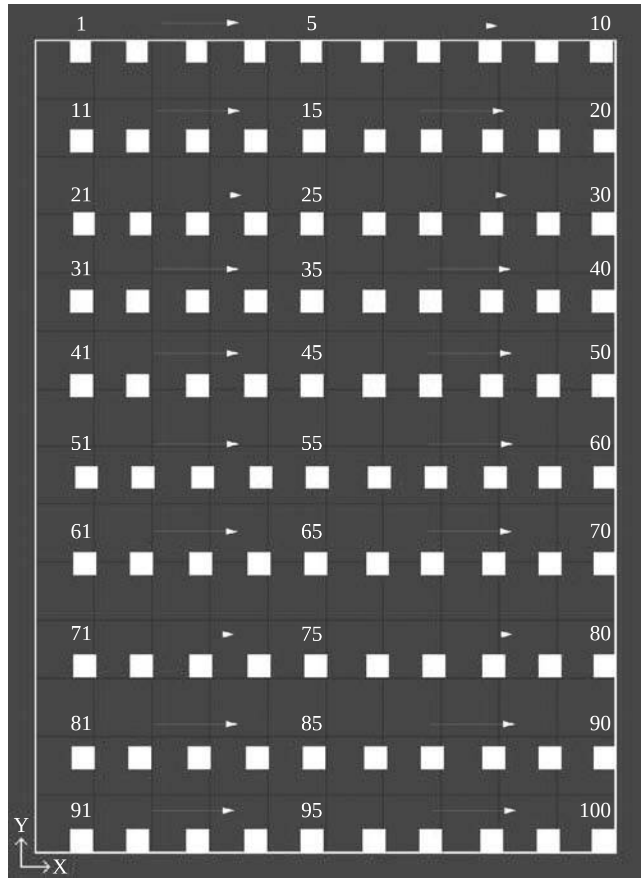


Table I

X (mm)	**Y (mm)**	**Z (mm)**
0.2043	0.1758	0.2095

Experiment 2b: calibration of the printer parameter setting for a reduced part of the 3D-printer workspace

The small dispersion of the measured values from experiment 2 lead us to assume that a calibration for a smaller building area leads to better results. This assumption was examined in the following experiment. About 15 cubes were lined up, three cubes each in five rows along the y-axis. The rows and the cubes were evenly distributed in the workspace area (Figure 5). The results from experiment 2 were used for the calibration of the binder settings. The half of the mean deviations of the edge lengths $\bar{m}$ for each of the three directions in space was used as binder compensation d_x in the settings of the printer. These settings were stored as new powder settings.

The established bleed compensation settings are shown in Table II.

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Figure 5 Positioning of $N = 15$ cubes in center of the building area of the 3D-printer

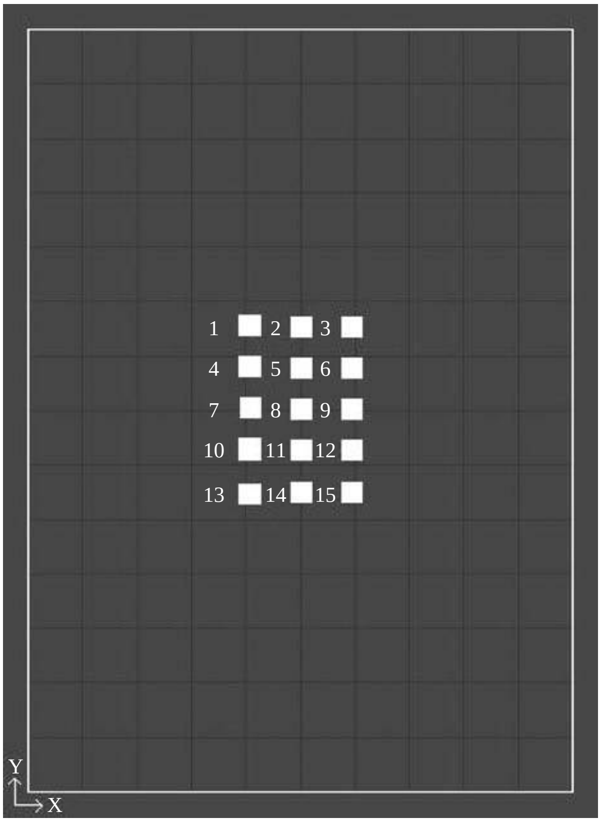


Table II

X (mm)	*Y* (mm)	*Z* (mm)
0.20933333	0.175	0.134

Results

Experiment 1a: verification of the direction dependency of the deviations in the entire building area of the printer

The results of the experiment are presented in Table III. The deviations from the set value of the cube amounted to approx. 0.4 mm in all three directions in space. The high-standard deviation in relation to the other directions in space was observed in z-direction.

Table III Result of the measurement of the $N = 100$ cubes

	X (mm)	*Y* (mm)	*Z* (mm)
$\bar{m}$	10.41	10.35	10.42
S	0.04	0.04	0.19

Notes: The cubes were printed with standard settings over the entire building area of the printer. The edge length of the 3D-models of the cube (set value) were 10 mm. The average value $\bar{m}$ and the standard deviations are presented

The graphic evaluation of the cube edge length shows the strong position dependency of the cube edge length in z-direction. The x- and y-cube edge length is relatively constant over the building area. In Figures 6-8 the individual edge lengths of the printed cubes are presented in their position within the workspace. The edge lengths in x, y and z are presented as separate plot.

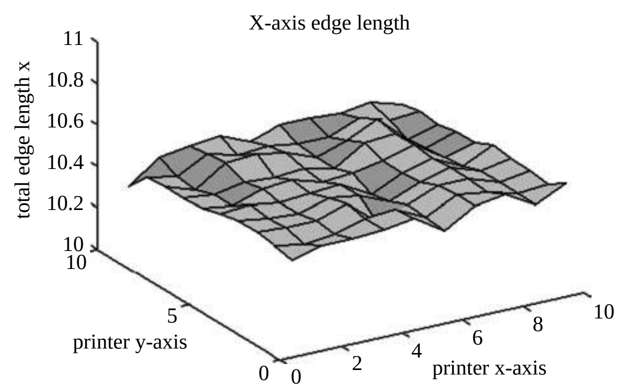
Experiment 1b: calibration of the entire printer workspace

The result of the experiment is presented in Table IV. The deviations from the set value of the cube were 0.24 mm in z-direction. In x- and y-directions the deviations were significantly smaller.

Experiment 2a: verification of the deviations for a reduced building area

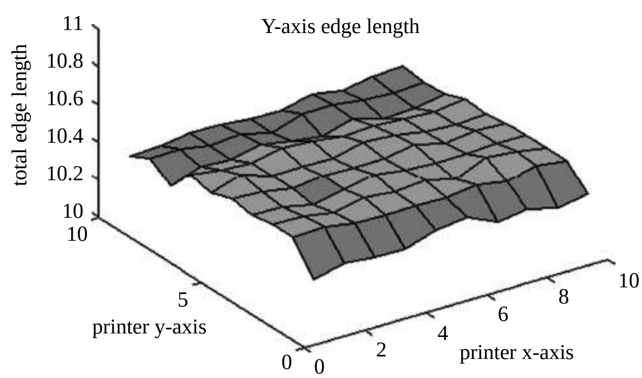
The result of the experiment is given in Table V. The deviations from the set value of the cube were approx. 0.4 mm in x- and y-directions. The deviation in z-direction were 0.27 mm. The standard deviation of the average values in x-direction and particularly in z-direction is substantially smaller than the results obtained using the entire building area.

Figure 6 Representation of the x-edge length of the cubes over the entire building area of the printer



Note: The values are relatively constant over the entire area

Figure 7 Representation of the y-edge length of the cubes over the entire building area of the printer



Note: The reduction of the y-edge lengths at the upper and lower end of the building area (y-direction of the printer coordinate system) is remarkable

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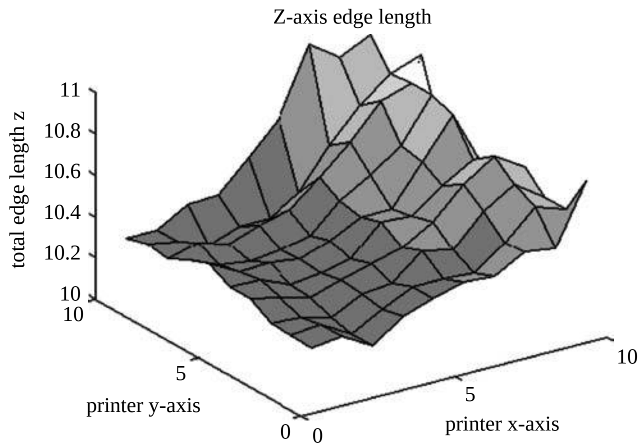
Figure 8 Representation of the *z*-edge length of the cubes over the entire building area of the printer



Note: The strong increase of the z-edge lengths in the upper end of the right side of the building area (y-direction of the printer coordinate system) is remarkable

Table IV Result of the measurement of the $N = 15$ cubes

	X (mm)	*Y* (mm)	*Z* (mm)
$\bar{m}$	10.03	10.00	9.76
S	0.02	0.03	0.02

Notes: The cubes were printed with calibrated binder settings in the center of the building area of the printer. The edge length of the 3D-models of the cube (set value) is 10 mm. The average value $\bar{m}$ and the standard deviations are shown

Table V Result of the measurement of the $N = 15$ cubes

	X (mm)	*Y* (mm)	*Z* (mm)
$\bar{m}$	10.42	10.35	10.27
S	0.01	0.04	0.02

Notes: The cubes were printed with standard settings in the center of the building area of the printer. The edge length of the 3D-models of the cube (set value) were 10 mm. The average value $\bar{m}$ and the standard deviations are shown

Experiment 2b: calibration for a reduced printer workspace

The result of the experiment is presented in Table VI. The deviations from the set value of the cube edge length were approx. 0.02 mm $\pm$0.03 mm in *x*-, *y*- and *z*-direction.

Table VI Result of the measurement of the $N = 15$ cubes

	X (mm)	*Y* (mm)	*Z* (mm)
$\bar{m}$	10.02	9.99	10.02
s	0.02	0.02	0.03

Notes: The cubes were printed with calibrated binder settings in the center of the building area of the printer. The edge length of the 3D-models of the cube (set value) were 10 mm. The average value and the standard deviations are given

The deviations of the printed cubes from the construction data (10 mm) were smaller than during the calibration over the entire building area of the printer.

Discussion

As expected, the results show that the achievable accuracy can be increased by adjustment of the printer parameters. It should be noted that the deviation of the edge lengths of the printed cubes deviate only by 0.02 mm from the set values. This deviation lies below the measuring accuracy of the measuring instrument used. The resolution of the used powder is 0.1 mm.

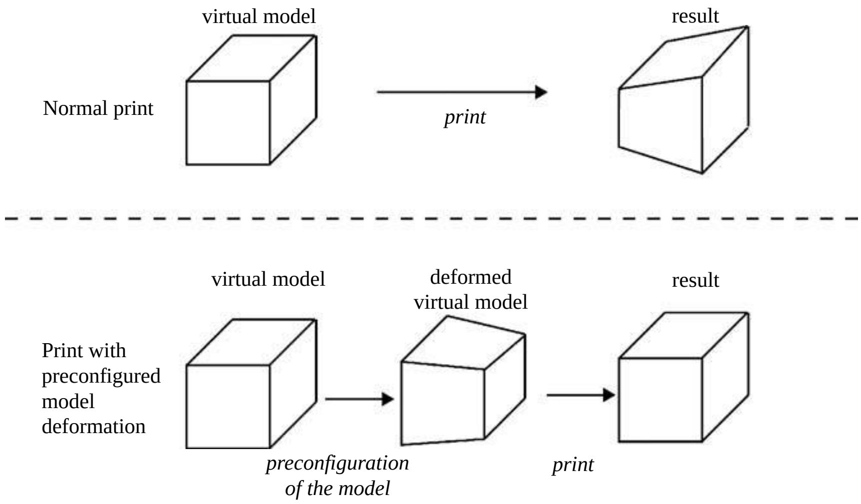
The results from experiment 1 show that the printer accuracy is as expected in terms of direction dependence. However, the position dependency has a greater influence on the result. Here, the *x*-direction in the workspace of the printer plays a major role. The *x*-direction corresponds to the direction of movement of the roller of the printer.

For the printing of smaller parts it is sufficient to determine the deviations by a test print with cubes and to adjust the binder settings. This was shown with test cubes in the center of the building area. These occupied a distribution area of approx. 90 × 50 mm. The print must then take place in the same location, in which the test cubes were printed. For the printing of larger parts the position dependency of the printer accuracy must be considered. This cannot be accounted for with printer parameters alone. In order to achieve uniform print quality over the entire workspace, the authors suggest the following:

- Print of test cubes over the whole printer workspace.
- Measuring of length of edge of printed test cubes.
- Input the calculated values, along with the direction and position information, into pre-print software.
- Loading the model into the software.
- The software configures and deforms the model preliminary according to the measured deviations between model and print. Missing values will be interpolated.
- Print the adjusted model.

The purposed process and comparison to the "normal" print process is shown in Figure 9.

Figure 9 Comparison between "normal" print of a model and the purposed print with a preliminary configuration (preconfiguration) of the model to compensate the known printer inaccuracies



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