Title:
New Method for the Application of Voxels in Product Design for Multi-Material 3D-Printing

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Introduction:

In conventional manufacturing, components are manufactured by removing material from a blank (subtractive manufacturing) or by reshaping a blank (formative manufacturing). Accordingly, CAD systems are used in product development, in which the components are also understood as solid bodies made of one material. In addition to conventional manufacturing, additive manufacturing has become increasingly important in recent years. The essential feature is that the components are created by applying layers of material [3].

In the meantime, new additive processes, such as e.g. 3D multi-material printing on the market. This method allows, for example, different colors to be used by combinations of differently colored filaments. In demanding applications, however, different materials can be applied in pure form or as a mixture - also called “digital material”. Theoretically, the product designer can now use any material anywhere on a component. This type of manufacturing can no longer be represented with a CAD system that uses only a simple solid body made from only one material. It is therefore necessary to use new CAD systems in which a component consists of a large number of small elements. These small elements, also called voxels, can then be made with different materials depending on their function.

In order to be able to offer the product designer the possibility of 3D printing using voxels, a new method is being developed starting from the component design, through the print preparation up to the 3D printing. During the method, there will always be a visible 3D model of the component to make it easier for the product designer to design the component and manipulate the voxels. The presentation of the method chain and the more detailed description of the components should provide an overall overview of the method developed for user-friendly 3D multi-material printing using voxel instead of solid bodies.

Literature Review:

The first approaches to the development of voxels were made in 1993 by Kaufmann et al. These showed the possibilities of voxelizing images using grids [6]. Chandru et al. transferred these findings to additive manufacturing because they recognized the connection between layered structure and voxel-based representation of components [1]. Current research by Faieghi et al. shows the great importance of voxel-CAD for 3D printing [2]. Zhou and Zheng also show the use of voxels for special features, such as the minimum wall thickness and the use of multi-material 3D printing [10].

To show a current example of the potential of digital materials, Swetly et al. tested the impact strength of a digital material compared to a material that consists of only one component. The digital material was composed of a hard, brittle material and an elastomeric material in a checkerboard pattern and generatively manufactured using the PolyJet process [9]. The results clearly show that for all edge lengths tested, the samples from the mixed material have a significantly higher impact resistance than the samples from one material. Zhu et al. see the material selection, the material distribution and the arrangement of the materials within the component as a great challenge. Further research work had to be carried out here in order to be able to precisely predict and define the achievable material properties [11].

Modeling with voxels is also used, for example, in the development of 4D printed components. An example of this is a body network. If this is made of smart materials, it can assemble itself under the influence of an external stimulus and without any additional aids [7]. According to Sossou et al. modeling with voxels is suitable for designing smart materials. The voxels are used in software to design the smart materials virtually and to expose them to certain stimuli. An example is a valve that is placed in water and opens and closes based on the temperature of the water. If the temperature rises, the components contract and close the valve. If the stimulus is removed, the initial state is restored and the valve opens again [8].

Hiller and Lipson describe the modeling of any complex component using voxels as a tool with great potential. The authors see the printing of compact, integrated network chips in just one production step as a possible field of application for voxel modeling in connection with 3D multi-material printing and the resulting digital materials. The voxels to be used are insulating, conductive or other electrical components [4].

In the investigations by Junk and Einloth, a simple example was used to show that a continuous process chain from 3D design using a Voxel-CAD-system to multi material printing is applicable. This makes it possible to produce useful components with locally different properties in one piece. However, these preliminary results are unsatisfactory, since the Voxel CAD system requires a high level of technical effort and a geometrically imprecise result due to the discretization [5].

Method for the application of voxel in product design:

The process chain for this new method of user-friendly 3D printing using voxel can be seen in Figure 1. Furthermore, the software used and the file formats for the interfaces are shown in Figure 1. First, an overview of the entire method chain is created. The post-processing of the additively manufactured components is not explained in detail at this point, since the design and printing process of the components are in focus of this contribution.

In the first step, the 3D model of the component is designed using a volume-based CAD system such as CATIA V5. The results of Junk and Einloth [5] show that volume-based CAD systems are more suitable for the design of components than voxel-based CAD systems. For this reason, the component should be designed in a volume-based CAD system.

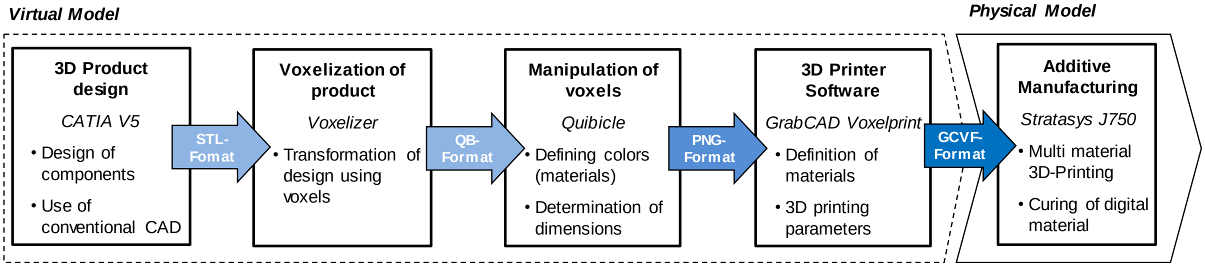

Fig. 1: Process chain for user-friendly 3D printing using voxels.

When the 3D model of the component has been completed, the STL file of the component is exported from the volume-based CAD system and then imported into the software “Voxelizer”. This website offers the possibility of importing STL files and exporting them into specific formats that depict the component using voxels. At the same time, the resolution of the components can be determined. In general, this should be chosen as high as possible for reasons of accuracy and to avoid loss of information about the contours of the component. In order to be able to export the component to the software “Qubicle”, the QB file format must be created. This method represents the second step, which saves the user the high design effort in voxel-based CAD systems.

The voxel-based CAD system “Qubicle” is then opened and the QB file of the component just created is imported and opened. Since the component now consists of voxels, each voxel or entire voxel areas can be edited in “Qubicle”. Editing means the coloring of the voxel, since the selected color later corresponds to a material assigned to the color. The user must therefore already consider which materials he intends to use in which component areas in order to define the desired component properties at these areas. The voxel-based CAD systems are ideal for processing the component at the voxel level, since they offer an easy-to-use, clear and user-friendly interface for processing the voxel. In addition, the user always has a complete 3D model of the component on the screen.

As soon as the processing of the voxel is completed, the component must be dimensioned for the subsequent 3D printing. It is crucial to choose the correct size, since the size of the matrix in “Qubicle”, in which the component is represented, determines the format of the later PNG files. To get the height of the matrix, a calculation is performed, how many PNG files or slices are needed for later printing. The component height in mm is divided by the layer thickness of the printer of 0.027 mm.

Since “Qubicle” creates a PNG file for each layer for each voxel in the vertical Z direction, the number of voxels in the Z direction has to be determined. “Qubicle's” scaling function is very useful in this method because each layer and the voxels it contains are ultimately only multiplied by the entered factor. Thus, there is no loss of information about the voxels of the different levels when scaling the height of the component. However, you can only scale with integers in “Qubicle”. As a result, due to rounding errors, it is usually not possible to fully adhere to the real component dimensions.

When dimensioning the width and length of the component, it must be considered that the later resolution of the J750 when printing is 600 dots per inch (DPI) in the X direction and 300 DPI in the Y direction. When exporting the layers, “Qubicle” allows the user to define how many pixels are to be used to represent a voxel. For example, if a PNG file has the dimensions (600 x 300) pixels, the printed layer would have the dimensions (25.4 mm x 25.4 mm) with a layer thickness of 0.027 mm. Taking this into account, the component dimensions must be converted from mm to pixels and the component must be scaled accordingly in the X and Y directions. Here too, only whole numbers can be used to scale the width and length of the component in “Qubicle”.

After the dimensioning of the component has been completed, it can be exported using the “Qubicle” slice export function in the form of PNG files. The PNG files are numbered in ascending order and saved in a target folder. It is also possible to choose how many pixels are used to represent a voxel. This can also be helpful when scaling the component. When this process is completed, the PNG files created by “Qubicle” are loaded into “GrabCAD Voxel Print” from Stratasys. Finally, the necessary settings for generating the printable file must be made within this software. This includes assigning the printer's materials to the colors recognized by software in the PNG files. If this has been successfully completed, the component can be printed.

Example of use for the new method:

The developed method is demonstrated in this chapter using a practical example. One wheel serves as a sample component for the application of the new method. The method aims to offer the product designer the possibility of manipulating the voxels of a component. The focus is therefore not on the achieved or achievable component properties as a consequence of the manipulation of the voxel. The goal is to achieve user-friendly 3D printing using voxels. The first step is the design of the 3D model using a conventional, volume-based CAD system (CATIA), as shown in Figure 2a.

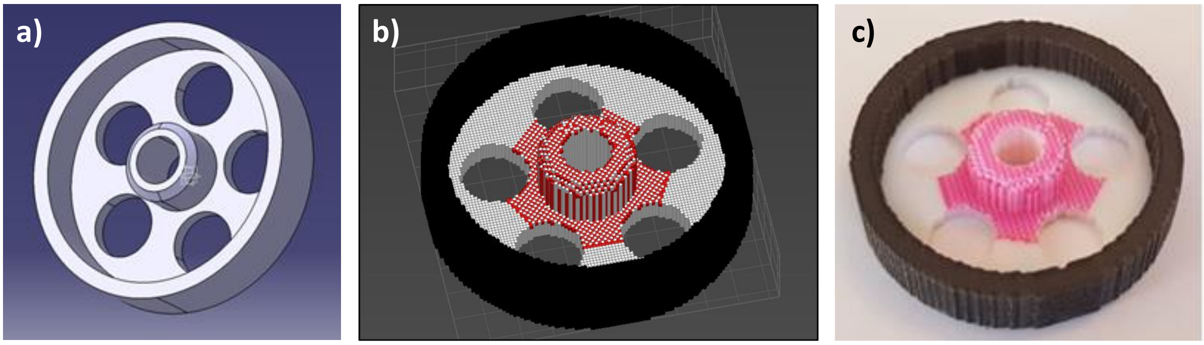

Fig. 2: a) CAD-Modell of the sample component using conventional CAD-System, b) Manipulation of voxels using Software "Qubicle", c) 3D multi material printing of the wheel.

In the second step, the browser is opened and the "Voxelizer" website is opened. The website can display STL or OBJ files using voxels and export them in different formats. The generated STL file from CATIA V5 is imported and the target format QB is selected for use in "Qubicle". In order to get the closest possible approximation, the dimensioning and therefore the resolution must be determined at this point, since only integer multiples can later be used to scale the component in "Qubicle". The wheel in this example has a total diameter of 35 mm. The resolution is set to 103 voxels. The particular feature should also be activated to fill the interior of the component. Thereafter, the scaling of the component in "Qubicle" will be adjusted in order to ultimately achieve the correct dimensions again.

The next step is to import the file into "Quibicle". The dimension of the matrix in "Qubicle" corresponds to the dimensions defined in "Voxelizer". Now the voxels of the component can be manipulated and edited according to certain target variables using the functions of "Qubicle". The user always has access to the complete 3D model of the component. This is descriptive and extremely helpful during the processing of the component. Figure 2b shows a finished example of the JetMobil wheel, in which three different colors are used. Various patterns have also been incorporated to illustrate that each voxel of the component can be manipulated.

Once the processing is complete, the correct dimensioning of the component follows in order to correspond to the specified dimensions of the technical drawing. The component is then sliced into 296 PNG files using "Qubicle's" slice export function. The basis for using the voxel printing software "GrabCAD Voxel Print" is created by generating the PNG files for displaying the layers of the component. The print preparation software must now be opened to check the color setting. The desired materials are then assigned to the recognized pixel colors. The component is then loaded into the installation space of the 3D printer and the geometry is checked.

Finally, 3D printing is started and the component is generatively manufactured using a 3D multi material printer Stratasys J750 (see Figure 2c). Small deviations of approx. 0.15 to 0.4 mm in comparison of the 3D printed component to the technical drawing can be measured. The deviations are caused by the rounding due to voxelization and scaling during the previous process steps.

Conclusions:

After the developed method has been carried out, it becomes evident that the specified dimensions of the component can only be approximated. The deviation is based on the necessary rounding of the calculated numbers for scaling the component, since only whole numbers can be used for scaling in "Qubicle". If the effort to design the component is considered, the product designer bypasses the complex design in a voxel-based CAD system. Instead, a volume-based CAD system is used, which considerably simplifies and shortens the product development process.

The simple and user-friendly manipulation of the voxel in "Qubicle" gives the user complete control over the design and distribution of the materials on the component. For the subsequent dimensioning of the component, a one-off calculation must be carried out for the corresponding component. The scaling of the component does not lead to any loss of information about the contained voxels. In summary, it can be stated that with the presented method, the complex process of 3D multi-material printing using voxels can be realized with reasonable effort and sufficient accuracy.

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