June 2013. Vol. 3, No. 4 ISSN2305-8269
International Journal of Engineering and Applied Sciences

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APPROACHES FOR THE LAYER DATA GENERATION FOR SPECIAL ADDITIVE MANUFACTURING APPLICATIONS

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ABSTRACT

A key advantage of layered manufacturing, especially laser beam melting, is the capability to manufacture thin and lightweight structures. Hence, the state of the art data exchange uses STL files in order to transfer the designed CAD models to the machine. This limits the user when special geometries should be manufactured as surface models without volume cannot be processed. Due to these limitations a direct slicing approach has been developed. This approach uses the native CAD data for the generation of the slice files. Therefore the STL files become redundant. This approach leads to new fields of application for parts manufactured by use of laser beam melting. Furthermore an STL-less approach for the investigation of grid structures for filter elements e. g. is discussed.

Keywords: Additive Manufacturing, Rapid Manufacturing, Laser Beam Melting, Direct Slicing, STL, Grid Structures, Thin Walled Structures, Knowledge Fusion, NX, Porous Structures

INTRODUCTION

Additive Manufacturing (AM), also known as Rapid Prototyping (RP), Layered Manufacturing (LM) or Solid Freeform Fabrication (SFF), is becoming more and more important for today's product development processes [1]. In the past "Conventional" production techniques like machining or casting seemed to be nearly exploited. Therefore many users consider "new" technologies like AM capable of solving a lot of problems caused by "conventional" production techniques. However, deeper verifications of the prospects of this technology lead to a more negative approach. In fact, AM technology does not meet all technical and operating requirements for routine business operations. Standards and guidelines, like rules for verifying the manufactured workpieces, are still insufficient. The VDI-guideline 3404 "Additive fabrication - Rapid technologies (rapid prototyping) - Fundamentals, terms and definitions, quality parameters, supply agreements" and the ASTM F2792 - 12a "Standard Terminology for Additive Manufacturing Technologies" mark the first necessary steps by describing basic information and nomenclature [2; 3]. Due to these reasons AM is particularly used for prototyping applications nowadays. Beside this, Rapid Tooling (RT) for tool and mould manufacturing is a growing field of application.

When this technology is to be developed for manufacturing processes, the advantages must be outlined in order to overcome restraints due to uncertainties. Therefore the common description Rapid Prototyping is the wrong approach which leads to misconstructions. By using this technology, the product manufacturing is not necessarily faster compared with "conventional" technologies. Turning or milling e. g. deliver far better performance when the part geometry is simple. Therefore this technology should not be applied for parts that easily can be made by use of other technologies. But with growing complexity of the part geometry, AM becomes more effective. Beyond that,

ISSN2305-8269
International Journal of Engineering and Applied Sciences

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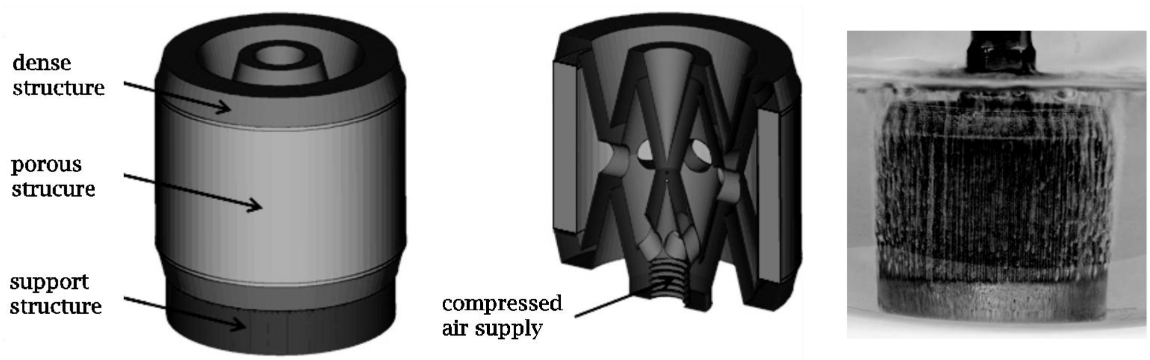
the characteristic additive build-up provides the opportunity to manufacture a defined geometry that cannot be manufactured with other technologies in an effective way.

Application examples are filter elements. Recent research has proved that AM technologies like laser beam melting are feasible to build filter structures which are comparable to conventionally made porosities [4]. The main advantage of AM in this case is the ability to manufacture filter structures integrated in other parts, without the need of joining. In order to prove this approach, SEHRT designed a round test cylinder with a defined porous structure and manufactured it by mean of laser beam melting. Figure 1 shows this part and the affiliated test [4].



a) design of the round test cylinder

b) perfusion of compressed air

Figure 1: Round test cylinder [4]

In the shown example, the filter structures were manufactured with the use of different hatch distances in combination with special process parameters. However, the hatch geometry is generated automatically during the pre-process and the different STL files of the filter and the solid geometry files have to be joined to one part during the build process. Although the results showed that this approach leads to applicable filters, the geometry of the filter structure still depends on the hatch geometry supplied with the AM machine affiliated software.

A further example is the creation of thin and lightweight structures e. g. for the conformal cooling of turbine blades. Laser beam melting delivers the feasibility to manufacture parts with thin structures in cavities. The problem occurring in this case is, that surfaces which have been created in the CAD system cannot be exchanged as STL files as STLs must consist of so called “waterproof” volumes. One of the designed test geometries is shown in figure 2.

This taken into account an approach for the CAD based creation of a geometry of this kind has been developed. In conjunction with the creation of the geometry, approaches for the data exchange between the CAD system and the pre-process software are investigated.

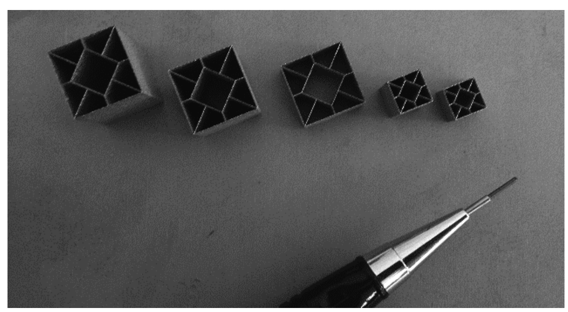


Figure 2: Test geometry for thin walled elements

Since 3D Systems developed the STL (originally STereoLithography, now Surface Tesselation Language) data format in 1987 it has come to be today´s de facto standard for the data exchange and geometry representation in AM processes. Even though the requirements for AM interface formats are rising constantly, there is no significant improvement of the STL data format [5]. Also the algorithms for the conversation of CAD data into STL files still do not deliver consistently high quality. Dependent on the used CAD system, conversation errors and syntactic representation errors such as gaps, overlapping triangles and incorrect orientation of normal vectors habitually occur [5; 6].

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The disadvantages of the STL format have led to several approaches for improvements. WU and CHEUNG e. g. presented an enhanced STL format which is able to store additional information while accuracy is increased [7]. In 2012, the ASTM has specified the AMF format (Additive Manufacturing File Format). This XML based format is an open standard for AM and is feasible for the storage of additional information like colours, materials and constellations [8]. However, these improved formats still have to convert the native CAD data before they can be processed. Subsequently these files are sliced. This complex procedure of data preparation is accepted and today's working solution for most AM applications. But as soon as it comes to highly specialized products with freeform surfaces these file formats linit the geometrical design of AM parts. Another disadvantage of the STL format is that it cannot offer the possibility to transfer more than the geometrical information. Additional model information like topological, process, material information or tolerances must be transferred in another way. Nevertheless, the STL format is a favoured and approved standard and is not likely to be replaced by a more capable format e. g. STEP [5].

As the STL format is not feasible to transfer product data for examples as described above another way was investigated. That way the interface format is left out and the CAD data is directly sliced in the CAD system. This approach is known as direct slicing (DS) (Figure 3).

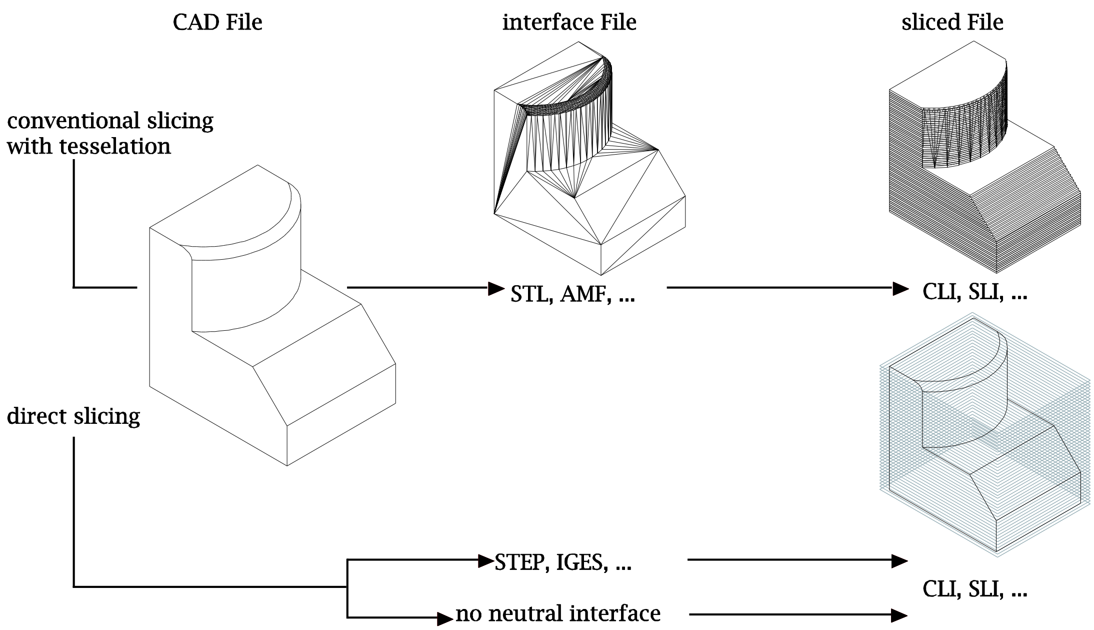

Figure 3: Conventional and direct slicing

DS or slicing in general can be categorized in two different approaches. The common way is to slice the parts uniformly with a constant layer thickness. Adaptive slicing delivers the opportunity to use different values for each layer. This adaption of the layer thickness regarding the part geometry leads to improvements such as reduced build time or growth of accuracy (Figure 4). Prior investigations have proven these advantages of DS [9]. However, due to the probed geometry adaptive slicing is not further investigated in this paper.

June 2013. Vol. 3, No. 4 ISSN2305-8269
International Journal of Engineering and Applied Sciences

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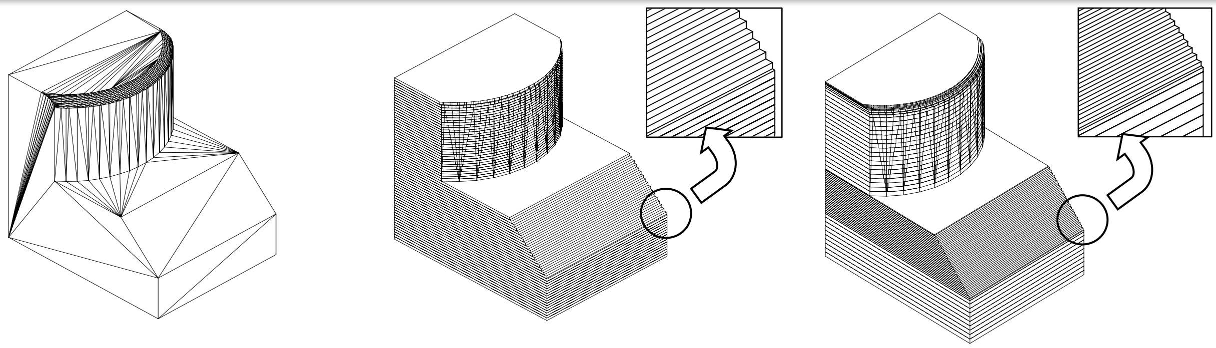

3D file (STL) b) uniform slicing (66 layers) c) adaptive slicing (60 layers)

Figure 4: Comparison of uniform (b) and adaptive slicing (c) based on STL geometry (a)

RELATED WORK

JAMIESON and HACKER identified the main advantages for DS e. g. a reduced file size compared with faced models, improved model accuracy, reduced pre-processing time and the elimination of repair routines due to STL errors. Nevertheless, the disadvantages like the loss of easy appliance of support structure to nested sections, the lack of model re-orientation, offset and beam compensation processing and the fact that more designer knowledge is needed were recognized [10]. Yet, they developed a slicing algorithm for the Parasolid kernel and exchanged the slice files as CLI. CHEN et al. used the PowerSHAPE modeler as CAD system for their approach. Here the section curves were represented by lines, arcs and Bezier curves, which improved the accuracy of each section (Figure 3) [11]. This was further developed to the application PDSlice for a commercial SLS (Selective Laser Sintering) machine [12]. SUN et al. created an adaptive DS method for PowerSHAPE based on the prior findings [13].

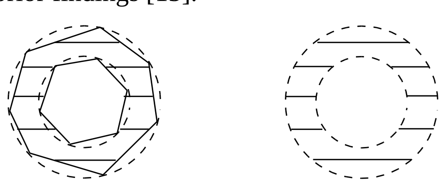

Figure 5: Comparison of (a) STL and (b) DS section, based on [11]

ZHAO and LAPERRIERE developed their approach with the objective to provide a relatively independent developer environment and regarding this their approach enables the user to read the cad model from different sources like DWG, SAT and DXF. In this case, necessary pre-processing steps are to be applied in the CAD-System itself (e. g. supports, scaling, merging, etc.); consecutively the geometry is sliced and the contours are exported as DXF [14]. CAO and MIYAMOTO applied the slicing algorithm DSlice for AutoCAD [15]. In 2007, CHAKRABORTY and CHOUDHURY presented an approach for DS of freeform surfaces. Here, specific problems such as multi peaks, self-intersections, multiple loops and saddles were solved [16].

PROBLEM DEFINITION

Regarding the afore described examples two different problems can be identified. For the filter elements and comparable grid structures DS obviously cannot be the only solution, because the definition of such tiny structures as CAD geometry with tools (e. g. pattern) will cause unnecessarily large files and a disproportionate amount of work. Therefore a solution for the definition and disposal of requested structures has to be found regarding these problems.

On behalf of the second problem for parts with thin walled non-manifold structures, STL export of the CAD designed structure is not possible because surface models cannot be processed in this way. Therefore a different solution for the generation of slice files and the disposal of this information to the AM machine is developed.

GRID STRUCTURES

In order to investigate desired grid structures for different applications and with different process parameters the grid lines have to be defined exactly by the user if the results are to be validated. Therefore, an application for the creation of CLI files is created. CLI is used for the data exchange because it delivers stable results when the data is exchanged with the laser beam melting machine used in this case. As the investigated grids only consist of line segments the CLI format delivers results with no loss of accuracy here.

June 2013. Vol. 3, No. 4 ISSN2305-8269
International Journal of Engineering and Applied Sciences

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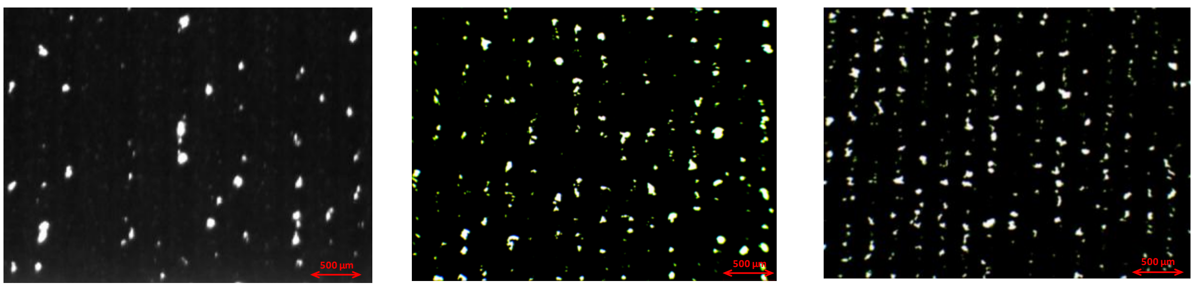
In this special case, the exact definition of the desired grid structures is requested, and therefore an EXCEL based approach is used. This enables the user to define exact coordinates and validate the manufactured parts after regarding his prior definitions. The application extracts the requested data and transfers it into CLI files which then need to be manufactured. One advantage here is the freedom of the design of each scan line.

In figure 6 b) and c) two lateral views of a single wall made of Hastelloy X are compared with a lateral view of a single wall structure made of stainless steel (cf. Figure 6 a)). The stainless steel structure in Figure 6 a) is made using the "normal" xy-hatch geometry and parameters supplied with the machine. The Hastelloy X structures are made using the above described approach by which the build parameters could be exactly defined and therefore the smallest available laser diameter is used. This is not possible in the case 6 a). Consecutively a significant improvement of the filter structure can be gained for the walls shown in Figure 6 b) and c). These walls are manufactured with the same build parameters like a) but with a variation of the filter geometry [17].



a) Stainless steel GP 1 b) Hastelloy X - aligned c) Hastelloy X – offset

Figure 6: Comparison of different wall structures [17]

THIN WALLED STRUCTURES

The main goal of this CAD based DS approach is a Graphical User Interface (GUI) supported CAD application which transfers the requested AM functionalities to the CAD user. The Application is integrated in the CAD System Siemens NX by the use of provided API functions. After defining the build direction by the user, the DS procedure directly generates the slice data as CLI file. The major disadvantage of CLI files is the fact that curved segments are represented as polylines. Nevertheless, CLI files have been proved as stable for subsequent laser beam melting pre-process steps.

With DS the geometry is sliced in the CAD system and the required polylines are generated in each layer. In this step, the amount of necessary points in each layer can also be reduced because straight lines only require one start and endpoint instead of mid-line points for the STL file. Hence, the amount of points in one layer is reduced and can be used for more accurate polygons of curved segments. Figure 7 compares the ways in which thin walled structures may be manufactured today in the "usual" way compared to DS. First the STL based approach is used. Because STL files must consist of volumes an assembly approach is used to manufacture the requested structure (Figure 7). Here, several files are assembled in order to get the walls as result when the fill laser is turned off for these parts during the manufacturing process. Due to the assembly of the 8 STL files, "double" walls are the result when the faces of the STL's are mated. This leads to a double exposure at these internal walls. This does not show the requested minimal thickness rates.

In order to overcome this problem, the DS approach is used. Here the original CAD geometry is sliced in the CAD system and only the requested walls are exported as one CLI file. In this case the double exposure is no longer necessary and the walls may be manufactured with almost half of the thickness compared with the STL approach. This is a key advantage for the structure of the parts which lead to this investigation. An additional effect of this approach is the reduction of the file size due to reduced line segments due to interceptions. In the shown example the line segments and endpoints can be reduced from 64 to 16. This again delivers the opportunity to overcome the disadvantage of the CLI file showing lower accuracy compared with other formats since curved segments may now be hashed in smaller segments without growth of the file size.

CAD INTEGRATION

In this case Siemens NX was used for the exemplary implementation. NX delivers powerful tools for the integration of approaches like this. In our case Knowledge Fusion (KF) was used for the DS approach

ISSN2305-8269
International Journal of Engineering and Applied Sciences

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with a Knowledge Based Engineering (KBE) solution. Using rule-based modeling techniques, implemented user knowledge, checking and analysis functions, and KBE extends feature oriented and parametric-associative product modeling [18]. In order to create a comprehensive solution not only a method for slicing is investigated, moreover a solution for a CLI import is developed in addition.

By using the KF functionalities the direct slicing approach in NX starts with the loading of the CAD part (Figure 8). One advantage here is that not only NX files can be processed. Each file which can be imported in advance can be processed here. These can be IGES or STEP when no native NX geometry is available.

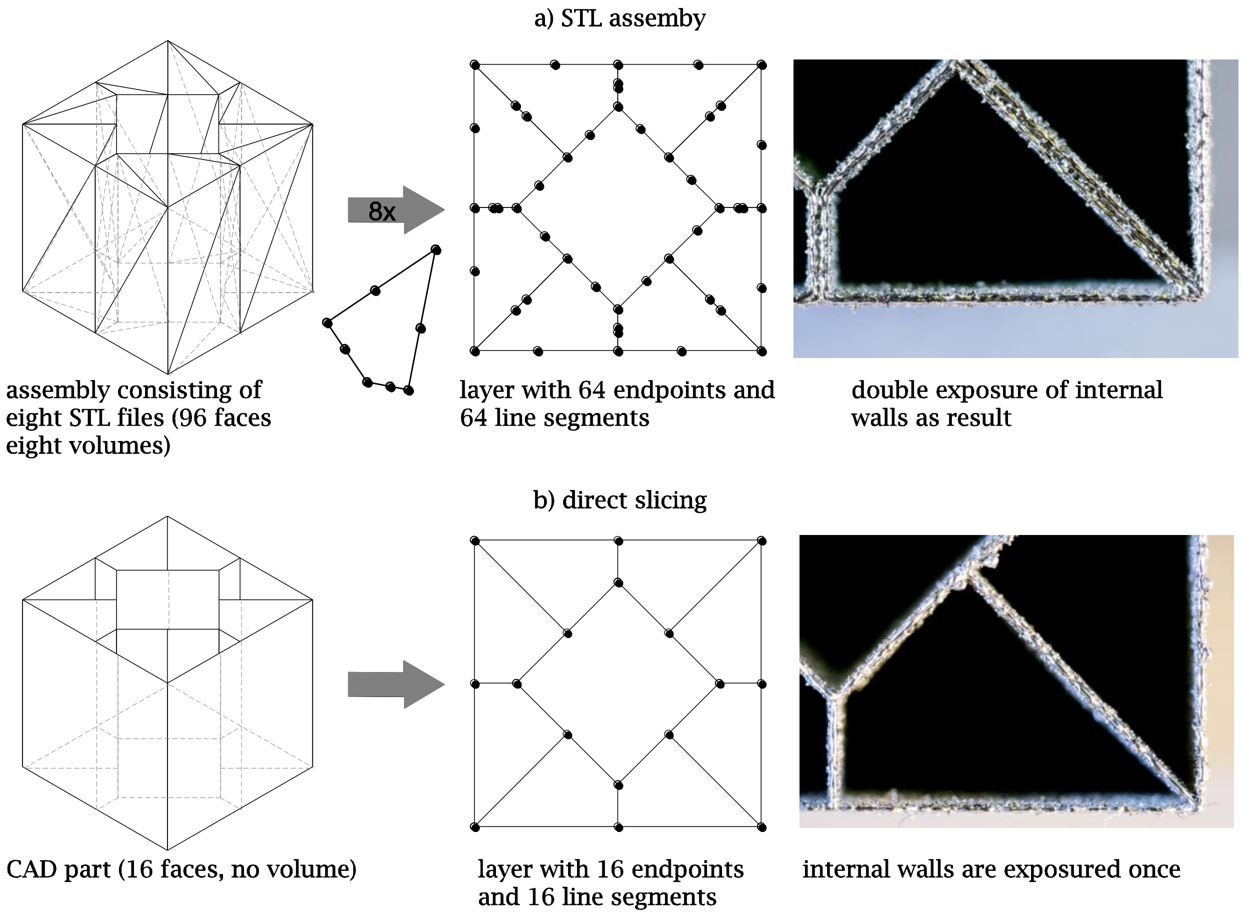

Figure 7: Thin walled design approaches

Then, the user input for the desired layer thickness follows. After this definition the user can decide if all parts and features are to be sliced or not. If specific bodies are selected the appropriate start plane for the layers has to be defined in addition. In other respects all available geometry in the opened part will be sliced in Z direction, starting with the XY plane. Therefore the NX function that creates intersection curves between planes and geometry is used. These intersection curves are then fragmented into line segments in order to create CLI-compatible data. Here NX provides a function which can be used to dispose points on curves. This function is used when curved segments are transferred into polygons.

Subsequently the created points are sorted in order to create an ASCII formatted CLI file. Therefore closed polylines are generated clockwise for outside contours and counter-clockwise for contours of holes. In both cases the part is always on the left of the polyline. Lines which cannot be stored as closed polylines are stored as straights with their start- and endpoint. This case especially occurs when non-manifold designs like the example shown in figure 7 are sliced.

Based on this approach, a method for the import of ASCII formatted CLI files is developed. This helps the user to validate the sliced geometry. Again NX functionalities are used to import the layer data. Then, layer by layer, the contours are created as sketches and then extruded by the layer thickness.

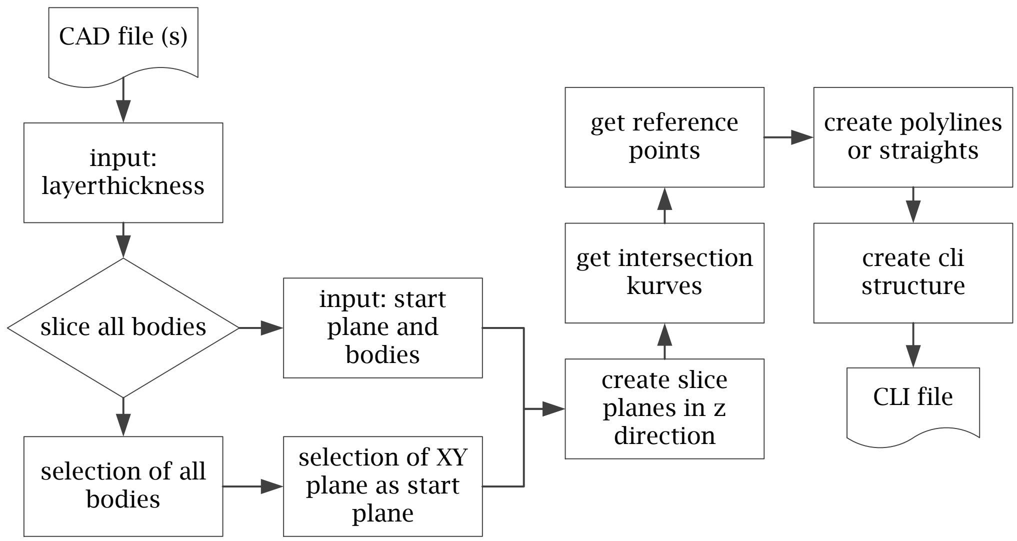

Figure 8: KF based direct slicing in NX

CONCLUSIONS

There is a number of advantages of the DS approach which can be identified for the case of thin walled structures. In such case, the main reason for this approach is that by using the STL format, surface models like the requested structures cannot be manufactured in a proper way. Especially for this reason this way for the direct export of slice data as CLI files was applied. First examinations of this approach have been very successful. Beside this main reason for the DS approach, additional advantages can be identified. With DS, the amount of generated process files is reduced as STL files are not required. This reduction simplifies the state of the art PDM/PLM process because less files and versions have to be handled. In addition, part quality can be enhanced. Furthermore, the native CAD geometry must not be tessellated before slicing and even adaptive slicing can be considered and implemented in this approach in the future (cf. paragraph two). However, the definition or the part orientation has to be done in the CAD environment by the CAD user first. At present this important step is usually applied during work preparation by the machine operator. Therefore, this knowledge must be provided to the CAD user. Knowledge Based Engineering (KBE) strategies deliver solutions for this problem. State of the art pre-process software delivers good results for AM based on STL files. Useful functionalities of these products are to be integrated in CAD systems provided that the DS approach should be accepted by the user. Therefore, feature-based support generation in the CAD environment is another possible extension.

The EXCEL based approach for the grid structures is also developed further. Here the user should be able to define several volumes in the CAD model which contain a special grid structure. This information is then used when the model is sliced and the requested scan lines are automatically generated in the slice file.

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