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Developing an Interpreter for the Implementing STEP-XML Enable Seamless Integration of Design and Additive Manufacturing

M. Lakshmi Sramika*[1], Dr. A. Bala Krishna[2], Dr. Ch. Srinivasa Rao[3]

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Abstract: Additive manufacturing (AM) presents significant advantages for industrial production, particularly in scenarios demanding intricate designs at small scales. Multiple research initiatives are currently advancing to enhance universal data formats. These efforts aim to enable developers and users alike to seamlessly organize, validate, and experiment with complete digital workflows, leveraging AM technologies' standardized interfaces and data frameworks. A key research focus involves developing an interpreter to convert STEP geometry files into XML format, optimized for compatibility with AM processes. This methodology is validated through practical experimentation using a 3D printer, which tests the interpreter across two distinct case studies. Modern manufacturing systems necessitate strategic methodologies and tools for product design and development. Efficient utilization of equipment and resources requires computational intelligence-based modeling, analysis, and optimization across industrial operations such as planning, design, operation, and control. The future expectations of the industry highlight a seamless process where a customer's natural language input is directly integrated into CAD/CAM software to generate the final product. This underscores the need for CAD/CAM engineers to incorporate artificial intelligence (AI), digital twin (DT), and allied technologies into the product development cycle. Achieving this integration enhances productivity and enables the production of high-quality, cost-effective products, thereby enhancing competitiveness and sustainability in the global market. This unified approach hinges on the tight integration of AI and digital twin technologies with all systems utilized in design and manufacturing. An interpreter is developed in the present work to integrate design geometry and additive manufacturing.

Keywords: *STEP, AMF, Interoperability, Additive manufacturing, CAD/CAM.*

1. Introduction:

Additive manufacturing has the capability to enhance design processes within the realm of development and data interchange. The existing approach encompasses distinct surfaces, autonomous wireframes, separate points, and tessellations of 3D solids. Initially, each tessellation will rely on a triangular structure, which will progress to a polygon-based tessellation in the subsequent phase. Vat photo polymerization denotes a technique where consecutive layers of entities are solidified at the base or surface of a vat containing liquid photopolymer through the utilization of a laser beam or alternative light-emitting source.

Charles Hull developed it in 1984 and later founded 3D Systems. Rapid prototyping, which was introduced in the 1980s to develop models and prototype parts, was the first method of creating a 3D object layer by layer using CAD. Rapid prototyping is one of the older additive manufacturing (AM) techniques. Human involvement, reduced time and cost and ultimately the product development cycle are some of the key advances of this method in product development. It is possible to capture intellectual ideas and develop them into extremely reliable products with the help of user-generated geometric STEP. The .STL and .STEP file formats can be used to export the geometry created in a CAD system. The tessellated geometry for the part created in the CAD system is included in these file formats. The most common use for STereoLithography (.STL) files is rapid prototyping. The geometric model data is exchanged with a heterogeneous modelling system via the STEP format [1]. Despite its popularity, the .STL format has a number of disadvantages, including lower accuracy and redundant data. To avoid these problems, an EXPRESS model was created as a STEP-NC ISO (14649) module [2].

The EXPRESS model has become an international protocol for the exchange of product model data with STEP between different systems in product development. STEP AP203 and AP214 are application protocols that contain exported design data from CAD systems. The implementation of STEP standards and the investigation of resources are carried out by many large companies. These protocols STEP-AP 203 and STEP AP-214 are being merged to develop a protocol called STEP AP-242, which is still under development. This protocol will be developed with additional features that can meet the requirements of advanced manufacturing. Building platforms for the

[1] *Department of Mechanical Engineering, College of Engineering, Andhra University, Vishakhapatnam, INDIA*
ORCID ID : 0000-0003-0097-6620
[2] *Professor, Department of Mechanical Engineering, SRKR Engineering College, INDIA.*
ORCID ID : 0000-0002-3440-2265
[3] *Professor, Department of Mechanical Engineering, College of Engineering, Andhra University, Vishakhapatnam, ,INDIA*
ORCID ID : 0000-0002-9683-8339
** Corresponding Author Email: sramikamuttamsetty@gmail.com*

integration of neutral file formats and new manufacturing formats has become the new trend. STEP-NC is one of these platforms that can prevent data loss. CAD-CAM-CNC systems are integrated to perform direct machining. The selection and optimization of parameters and the control of CNC actuators can be integrated into a single database to enable intelligent manufacturing [3]. By developing appropriate STEP standards, interoperability between CAD, CAM and other CAE systems can be developed. The conformity of these standards with the required norms can be tested with a software analysis tool [4]. Based on the STEP standards, researchers have developed goals and specifications for rapid prototyping [5]. The data flow between STEP-CAD-CAM and STEP-NC was realized by Xiao et al [6].

Qui et al [7] propose free access to 3D data between different participants in the collaboration. Instead of a "grant-deny" method, they proposed a multi-level format for data access. A method called P4M [8] developed by Reimeringer et al. manages processes and products on digital mock-up. In this method, products and processes are integrated using a graphonumeric parameter. For the transfer of data from STEP files to RP systems, a method for slicing the STEP file was proposed by Jee et al [9].Matta et al [10] have described the most important problems when transferring data from CAD/CAM systems to RP systems. Further developments that can be made in CAD/CAM RP systems were also discussed. The need for standards and the integration of CA-x and RP systems in the rapid prototyping industry has been discussed and explained by Jurrens et al [11]. To increase the accuracy of the prototype in rapid prototyping along the boundaries of the sliced layers, Jin et al, [12] developed a mixed tool path and also introduced an adaptive algorithm for nozzle speed.

Although there have been advances in additive manufacturing technology over the last decade, few attempts have been made to actually implement AM systems. This is due to the problems associated with traditional numerical control systems such as G-code and STL. The STEP-compliant NC system has been adapted by Bonnard et al [14] for the implementation and validation of the additive manufacturing model. This method offers several advantages, such as additive manufacturing directly from STEP-NC, hybrid processes such as machining and additive manufacturing, optimization and simulation modules. Since many methods of data visualization have been developed in academia, it is important to examine the completeness of these methods. Thoroughly analyzing these methods and comparing their strengths and weaknesses is essential. In this way, the future scope and appropriate direction of research in this area can be determined. In addition, the digital thread developed for additive manufacturing should be updated according to the sector in which it is used. The need for new and updated digital threads must be developed according to global standards. Before developing new digital threads, it is necessary to consider the state of the art of all developments during the last period of research [15, 16].Even with the increasing demand

for quality and speed in Industry 4.0, the integration of additive manufacturing with the inspection process helps to optimize the process. A closed digital loop that includes robotic inspection on the shop floor fulfils the quality requirements. The loop contains inspection data that is given as feedback to the design process, syntactically according to the neutral ISO10303 standard.

The digital thread containing STEP-NC data models has been integrated with the inspection process to achieve efficient and effective utilization of resources. An architecture has been developed to integrate the additive manufacturing process with the inspection feedback in syntactic form according to the ISO10303 standard. An integration method using digital data based on STEP-NC data was developed for closed-loop additive manufacturing [17]. Zivanovic et al. have developed a new methodology "RoboSTEP-NC" module according to ISO 10303-238 to enable machining with industrial robots [18].They have described a methodology for programming, simulation and robot-assisted machining. The developed RoboSTEP-NC module translates the programme into 3-axis machining using industrial robots according to the ISO 10303-238 standard. The developed method is verified by simulations on virtual robots configured on the STEP-NC machine software. It is expected that this method of using STEP-NC as the standard for machine tool programming will improve the efficiency of robot machining by taking full advantage of STEP-NC data.

There are many representations for geometry and tolerances in additive manufacturing. The gap between process-independent data and process-dependent data has been narrowed by the development of model-based data for additive manufacturing. There are many standards for additive manufacturing, e.g. for geometry, ASTM, STEP, 3MF, AMF and for tolerances (ASME Y14). Their implementation and improvement is important for the transfer of all the above-mentioned data to downstream manufacturing, long-term archiving and inspection. The concept of model-based engineering is based on the transition from 2D communication of geometry and manufacturing data to new digital 3D drawings, simulations and inspection methods, especially in the case of additive manufacturing [19].

The feature of MBE is a single data set that contains the entire digital 3D product model and associated product model definitions and can support downstream applications throughout the product's lifecycle. The benefits of the STEP-NC system and its future applications, developments such as hybrid manufacturing, flexibility, monitoring, knowledge and information sharing with efficiency and production optimization in a multi-process environment have been mentioned by Hamilton et al [20].Particular attention was paid to the SPAIM application, which maximizes the benefits of STEP-NC. By integrating STEP-NC into technical problems, the international standards are developed and the manufacturing sector is favoured with agility inside and outside the company. The applications implemented in STEP-NC are so advanced that industry CNCs can quickly become compatible with STEP-NC, increasing flexibility. Manufacturers can quickly make changes to the process plan, toolpaths, tool selection and part geometry to realise new capabilities that are directly linked to manufacturing. Manufacturers can respond quickly to changing demand from the rapidly growing competition in the industry. The further development of STEP-NC can optimize manufacturing conditions. A new STEP-NC standard for additive manufacturing was developed by Rodriguez et al [21], which generates a STEP-NC programme from the layer data of additive manufacturing in accordance with ISO 10303-AP 238. An adapter was developed to convert additive layer data into STEP-NC data. The simulation of the STEP-NC programme was carried out using software that has the machine software environment. Furthermore, the methodology was validated by implementing it on a real 3D printer and it was found to be suitable for additive manufacturing. STEP-NC programming and integration with product design data will be useful in reconfiguring and adapting the AM-NC industry to the new Industry 4.0.

Various geometric modelling methods and data exchange formats have been mentioned by Savio et al [22].Twelve geometric models were named and their advantages and limitations in terms of file size, opening and closing time were mentioned. Various tools that have been developed taking into account the advances in additive manufacturing were discussed. The new possibilities in the development of CAD tools for the current additive manufacturing technologies were also mentioned. NURBS and Mesh have shown the potential to manage the link between form and function in both boundary representation and volumetric representation methods. It was noted that little efficiency is achieved with current data exchange formats. There is a need to develop data exchange formats for handling volumetric representation methods, complex geometries, original geometry and hierarchical representations. The additive manufacturing method enables the production of complex shaped objects in less time with minimal material usage and low weight. This was achieved using two methods.On the one hand by adopting the grid type and on the other hand by optimizing the topology. A computerized model (using the finite element method) was used by Savio et al [23] to achieve the above objectives. They used six different cell types and two loading conditions for a cantilever beam configuration to verify the proposed new optimization method. The behavior of the system with the number of iterations of the model was investigated. The visual representation of the results in topology optimization was also mentioned.

The design of 3D meso-scale lattice structures (MSLS) is important for proper printing in additive manufacturing. MSLS are a series of 3D printed truss shapes made of unit cells that vary in size from 0.1 to 1 mm. Different stages in the development of the details of these MSLS were proposed by Graziosi et al [24] as a completely new method. In this process, the designers were guided to design the MSLS considering the manufacturing conditions. The recent trends of software developers and designers in the field of design for additive manufacturing were mentioned. The designers are encouraged to define new functionalities of MSLS, taking into account the impact of each phase on the overall design and manufacturing process. Their work consists mainly of developing different MSLS and standardizing the terms used in the design of lattice structures. The design phase consists of selecting the unit cell according to the functional requirements, dimensioning the unit cell according to the AM constraints, deciding the population in the component space, defining the MSLS density gradient and verification, followed by optimization of the MSLS.

The printing of functional gradient material (FGM) is also an emerging process in additive manufacturing. Garland et al [25] have printed FGM using a fused deposition modelling (FDM) 3D printer. This was achieved by controlling the speed of feeding two different filament materials into the melting chamber. All the design information mentioned above, which takes into account the manufacturing process, must be transferred to the manufacturing phase without loss of information. In order to transfer all this information between different CA-x systems, a suitable interface is required. Many of the future applications of STEP-NC in the integration of design and AM processes are aimed at the development of hybrid additive manufacturing processes such as machining and additive manufacturing, as well as the use of different materials in additive manufacturing. Advances in additive manufacturing require new visualization methods in CAD tools. The development of STEP-based interfaces is a current trend, as it is an international standard and a neutral file format that can be used to transfer data in the downstream manufacturing phase without data loss and loss of continuity.

2.0.METHODOLOGY:

String matching algorithm is implemented in the present work for extracting AM data from the STEP file and inserted into AM database. Express entities are base for generating STEP file. Express entity matching problem is to locate occurrences of entities in AM express entity pattern AMp=$c_1c_2c_3\ldots c_m$ in the given STEP file STEP_T=$t_1t_2t_3\ldots t_n$ over a finite alphabet Σ. Basically, this problem can be solved in two phases: pre-processing and searching. Pre-processing phase requires the efficient data structure to accommodate all entities of AMp. Meanwhile the searching phase compares the STEP file STEP_T with the structure of AMp.

2.1. AM-String Matching Algorithm

Basic Definitions

Definition 1 Let $AM_p=AM(e_1e_2e_3\ldots e_m)$ be the AM Express entity pattern, and AMe_k is the STEP Entity occurred in AMp at k_{th} position where $k=1,2,3,\ldots,m$. The STEP AM ENTITY AMe_k can be mapped into AMe_k: <k:0> iff $k<m$, or AMe_k:<k:1> iff $k=m$. Symbolically, AMe_k: <k:0> is represented by AMe: I_{k_0} and AMe_k:<k:1> is represented by AMe: I_{k_1}.

String matching algorithm is used to extract and separate the data related to a specific data model application. It also helps to find the mapping of topological and geometrical elements in various complex structures [13]. The exported data in the STEP AP 242 protocol is imported into interpreter program. Interpreter program separates the data associated with additive manufacturing from the data in STEP AP -242 and creates geometry database.

Additive manufacturing file format(AMF)

Although STL is the leading file format for additive manufacturing, using the AMF format could lead to more cost-effective machines for users and manufacturers. AMF is written in eXtensive Markup Language (XML) and can read features such as colour, material and texture maps that are not possible with other formats such as STL.

Preparing STEP file of the part:

First, the CAD model of the part to be 3D printed is created in a CAD system. The geometric model is tessellated and exported in the form of an .stp file. In addition to the geometry, colour and material colour and material data are also exported in the latest STEP AP 242 application protocol.

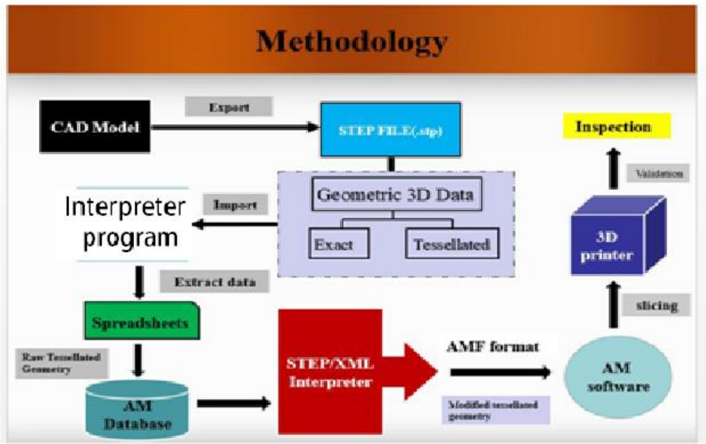


Fig.1: Process flow chart for STEP-XML-AM integration

Extracting data related to additive manufacturing:

The STEP file exported from CAD system is imported into STEP File interpreter program and the required module is selected from the tool. This tool creates spread sheets containing mapped entities of exact and tessellated geometry data. The data related to geometry is coded in green color as shown in Fig.2.

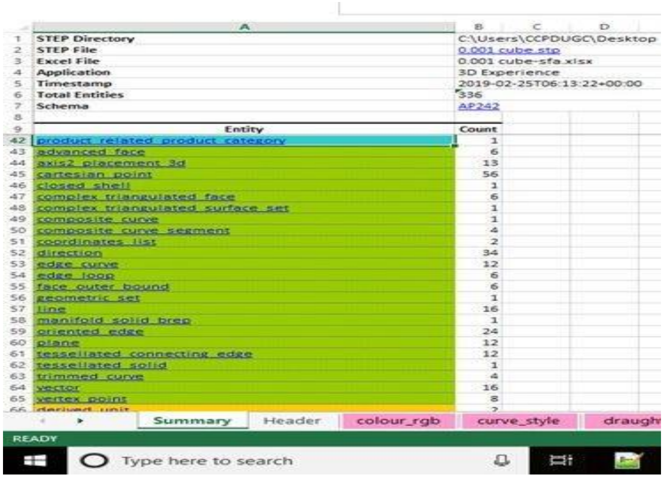


Fig 2: STEP file interpreter program

Load STEP file into STEP-XML interpreter: The STEP file is imported into STEP-XML interpreter using Load STEP file. It executes the entire STEP data and divides PDM, exact geometric and manufacturing Data and AM data. Each entity in the STEP file again splits into the required geometry format and it is saved in the database as shown in the Fig. 3.

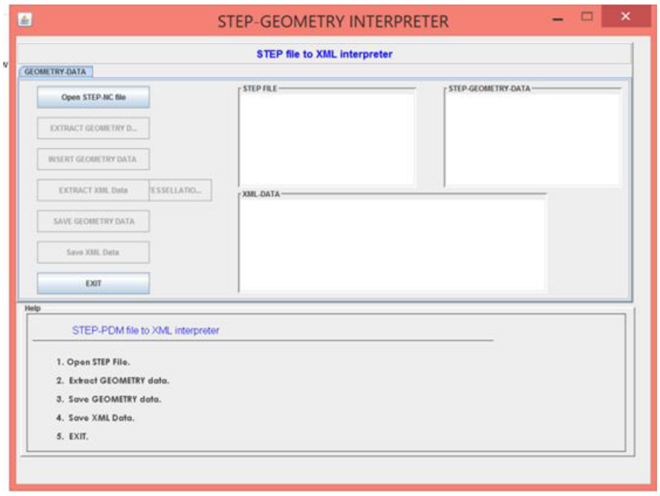


Fig.3 Template for Converting STEP files into XML file

Create AM Data: It separates AM data from the STEP file and writes AM data information in .txt format. Sample data is shown in Fig.4.

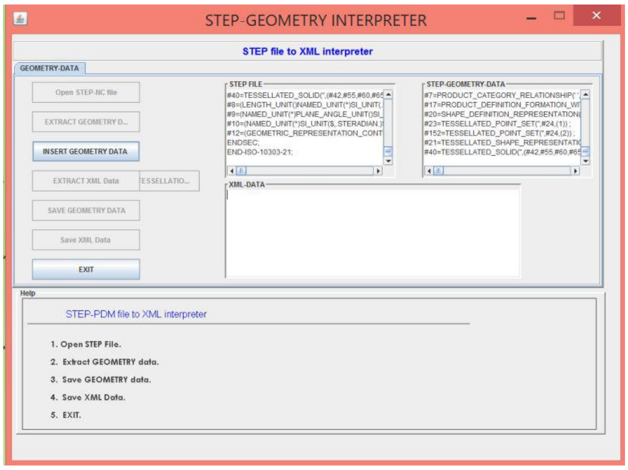
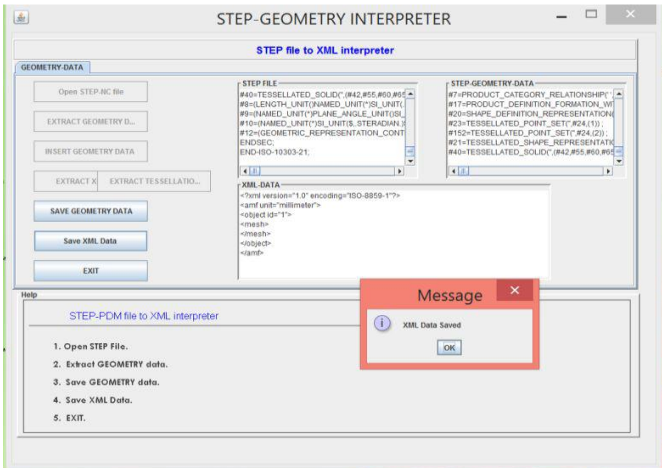


Fig.4. After separation of STEP-AM Data

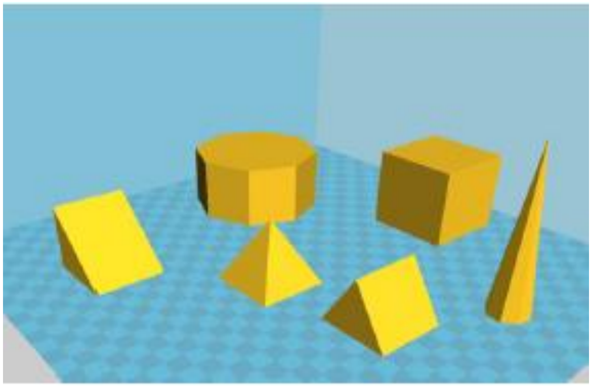
Save STEP Data and Save XML Data: After extraction of tessellated (AM) data, both commands are executed to save STEP data and XML data as shown in Fig.5.



3. Implementation and validation of STEP-XML-AM integration methodology

The STEP-XML-AM integration methodology is implemented for making three dimensional geometric primitives and propeller by using 3D printer. Sheet metal Solid models of these parts are prepared in CATIA and exported in the form of .stp files. CATIA models are shown in Fig. 6.

Propeller fan: A propeller fan is a 3-6 bladed impeller used to exhaust the air in industries or for home purposes. The impeller is rotated by a motor. The impeller blades are made by stainless steel. The impeller casing is made of cast alumimium. Some impellers are made with composite material using by Resin Transfer Molding (RTM). Some of the impellers are made by injection molding of fine metal powder. The above processes are time consuming and not affordable for prototype preparing stage of manufacturing. 3D printing of the above mechanical components reduces lead time and allows the firm to produce various types of prototypes. Some of the metal rapid prototyping processes are emerging; the production using such method can be rapid and be able to compete with regular manufacturing methods.



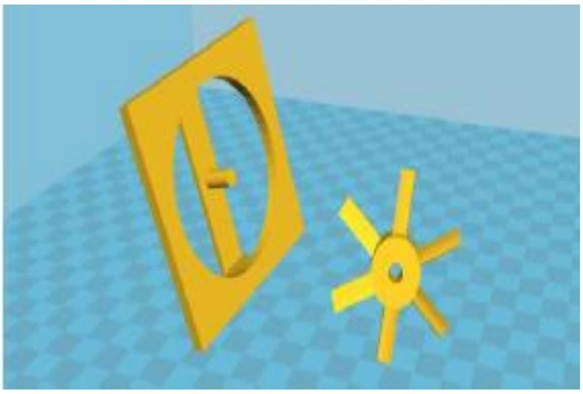


Fig. 6(a).CATIA model of simple 3D Geometrical Fig.6(b).CATIA model of propeller fan Parts

The STEP files produced by CATIA are then exported into STEP File Analyzer and Viewer. After extraction of Additive Manufacturing data, the STEP files are loaded in the STEP-XML interpreter. Here the data in EXPRESS schema is converted into XML schema. The screenshot of the output of the saved XML file is shown in the Fig. 7.

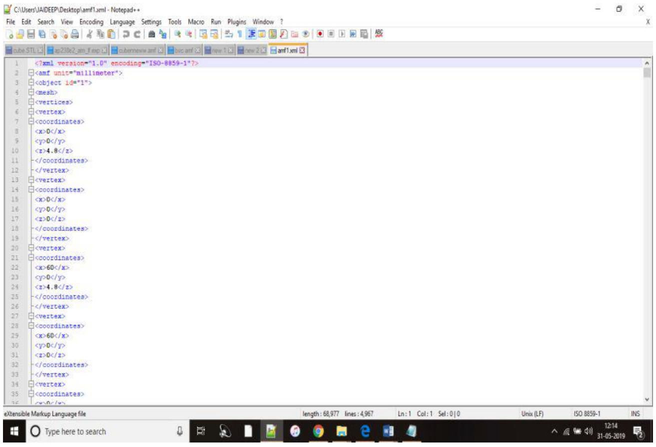


Fig. 7 Screenshot of XML output

Before Execution of the XML file in AMF software, validation process is done for output files (XML files) using online XML validation Software. Finally, the output file is mapped by its coordinates correctly along with its colour codes for each coordinate as shown in Fig.8. After successful validation of XML data, the actual printing is done. Fig. 9 shows the printed parts.

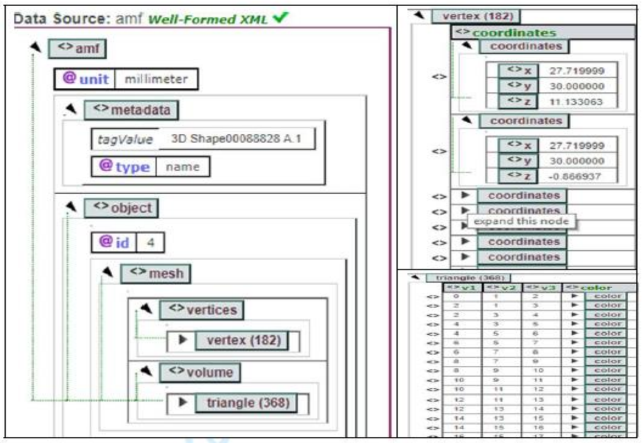


Fig. 8: Validation of output in XML view

Fig. 9 (a) 3D printed simple 3D geometrical parts

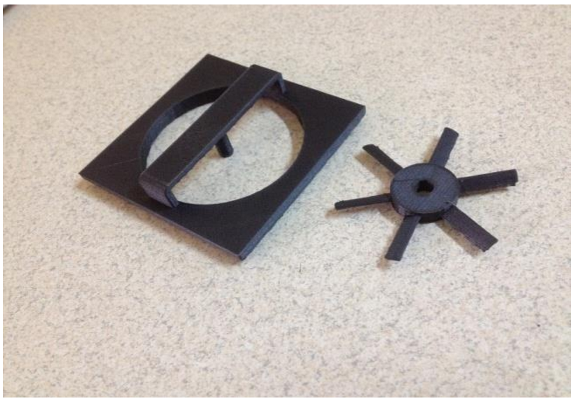


Fig.9 (b) 3D printed propeller fan

The continuities like G0, G1, and G2 are achieved by developing surface normal and curved surfaces. Fine tolerances can be achieved by this method with the developed code of continuity and succeeding development of STEP-XML interface. The surface normal is used instead of point normal and further fine tolerances are achieved by this method. The fillets given at edges of sharp corners are modeled with this surface normal by specifying relations among these surface normal. This is new and only available in this type of STEP-XML integration method.

Two different diffusers are used to get different combination of colors and achieve colored printing. This enables distinguish between various combined complex parts.

4. Conclusion

Design and additive manufacturing, particularly with the integration of STEP-AM, is heralded as one of the imminent industrial revolutions. The process of exchanging design data with 3D printers involves creating a database by extracting additive manufacturing data from STEP files using the STEP File Analyzer (SFA). The STEP XML interpreter then converts this data into an XML format readable by 3D printers. Geometric modelling of parts is performed in CATIA and exchanged via the STEP XML interpreter. The resulting file is validated using specialized software before the parts are 3D printed. This method enables colour printing and eliminates continuity problems and data loss.

With ongoing efforts to create direct XML file formats and facilitate data exchange between companies via the Internet, this approach aligns with current trends and supports collaborative development and production. The XML file is both human-readable and machine-readable. The developed STEP-XML interface promises precise production of prostheses from biomaterials. Limb data can be effectively exchanged over the Internet, allowing for precise remote manufacturing of prostheses to be used at the patient's location. This system also greatly benefits the production of medical and surgical instruments.

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