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Generative Design Software for Additive Manufacturing

David Town, Aristan Criard*

RMIT Centre for Additive Manufacture, RMIT University, Melbourne, Australia

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Abstract: The integration of generative design with additive manufacturing (AM) represents a significant advancement in digital fabrication and product optimization. The study at hand represents a comparative analysis of four most popular generative design software packages, including Autodesk Fusion 360, topology, Siemens NX, and SolidWorks/3DXpert, with regard to their relevant use and performance in AM workflows. Each of the tools was evaluated using standardized case studies and functional models in terms of usability, optimization, simulation integration, and AM compatibility, and output quality. The quantitative material consumption, weight decrease and print time were assessed together with the qualitative user feedback so as to generate a holistic analysis. The findings indicate that although all platforms have the ability to generate AM-ready components, they are all superior in different ways with respect to complexity, control, and integration of workflow. The paper puts a lot of stress on accurate software selection in association with design requirements and the capabilities of an organization. It is also the description of limitations and possibilities to achieve better interoperability, simulation accuracy, and automation existing now and in the future. The proposed work offers a workable guideline to engineers, designers, and other researchers desiring to implement or evaluate the use of generative design in AM-driven product development.

Keywords: Generative Design; Additive Manufacturing; Design Optimization; Lattice Structures; Topology Optimization; Simulation; 3D Printing; CAD Tools; Product Design; Digital Fabrication

1. Introduction

The development of Additive Manufacturing (AM), which is also referred to as 3D printing has disrupted the manufacturing sector in the sense that it facilitates the production of intricate geometrical structures directly out of digital data without any form of traditional tooling or machining. The switch in a paradigm of subtractive to additive has an enormous benefit such as less material would go to waste, design freedom would be higher, and developmental times shortened. AM has been used in many industries such as the aerospace industry, automotive industry, biomedical industry, consumer product industry, and constructive industry. The utilization of the full potential of AM, however, is pointless unless there is a parallel shift in how products are designed [1-3].

Conventionally product design has been a very laborous and repetitive exercise which has been limited by mass production methods of production. Computer-Aided Design (CAD) software available to designers allows one to create model parts and systems, but, in general, these programs are deterministic, and they depend strongly on user intuition, experience, and manual input. Consequently, designs that are made may not be optimised based on performance, cost, or the efficiency of the materials. That is why the role of generative design appears [4].

Generative design A computational design methodology that allows high performance design variations to be automatically generated using algorithms based on user-defined design constraints, including loads and environmental conditions, material properties and manufacturing processes. Such algorithms have the potential to output hundreds or even thousands of possible designs, quite frequently finding solutions that could never be envisaged by human designers. Generative design and AM are synergistic: complex geometries generated by the generative algorithms cannot normally be fabricated using other manufacturing processes and require AM, with no constraints on the complexity of the geometry, as in casting or machining [5].

Generative design combined with additive manufacturing opens up novel engineering and product design opportunities. Generative design may create significant returns in the performance of a part by performing optimization in terms of weight-to-strength ratios, thermal properties, or fluid flow. This is particularly critical in the case of an aerospace industry whereby saving the weight even by a slight margin can make a significant difference in terms of fuel savings and reducing the pollution. Medical, patient-specific implants and prosthetics have a definite advantage in organic shapes adapted to the human anatomy--designs perfectly adapted to both generative tools and AM processes of fabrication [6].

In addition, AM allows one to produce complex lattice and internal structures, which were hitherto beyond or were economically nonviable to be manufactured. Such structures can be automatically designed with a generative design program to cut down weight but not strength and stiffness. It also supports Design to Additive Manufacturing (DAM) the logic of which is that the product is developed and directly optimised toward the additive processes in the first place. Generative design and AM also combine, lowering design time and making prototyping costs more affordable, minimizing human errors and in many cases leading to superior performing products with a reduced impact on the environment [7].

Although all the mentioned is beneficial, generative design software in AM is not free of hurdles. The contemporary environment of generative design tools is un-coordinated with differing levels of abilities, sophistication, and compatibility with AM processes. Most of the existing solutions are either too specific, take quite some training to enable their use, or do not have a direct compatibility with AM systems. In addition, gaps can easily be uncovered during the translation between optimized-design and real-embodiment: in manufacturability, clash with slicing-software, or even fidelity loss when printed. The other issue is how to confirm the quality and reliability of these auto produced designs. Other outputs may not fulfil the functional requirements even though they are geometrically impressive, without proper simulation, analysis and feedback integration to the design. Analysing and comparing the generative design software tools, namely, considering their applicability to AM has not been fully exploited either. With industries becoming more automatized and optimized with each passing day, it is in the best interest to know which tools are available and how to restrict them in order to make better decisions [8].

The major aim of the study is to understand and discuss the performance of generative design programs towards additive manufacturing. The paper will determine and evaluate prominent generative design tools present in the market, determine assessment criteria based on viability, optimization functions, the ability to work with AM, simulation tools, and quality of output and carry out a practical case study or simulation using which generative design tools to evaluate output performance in producing AM-ready parts. It also tries to point out the strengths, limitations, and good-use situations of each tool when considering additive manufacturing and offer recommendations to the designers, engineers, and organizations who would want to incorporate the generative design into their AM processes. As part of the investigation, the research intends to fill the knowledge gap between computational design and the process practiced manufacturing, and thus will give a complete guide to practitioners as well as branch out in the discussion of intelligent manufacturing [9-11].

2. Materials and Methods

The methodology used in his research is the comparative evaluation approach that attempts to analyze the abilities of several generative design software solutions that are specifically designed or come compatible with additive manufacturing processes. The aim is meant to give a concise and working comprehension of the way in which such tools operate in situations that are usually controlled and reproducible when placed under practical design duties. It has four cycle of the methodology that include the selection of software tools, definition of evaluation criteria, development of test models or use cases, and a systematic collection of data related to the simulation and user experience [12].

2.1 Research Approach

This study takes a comparative analysis perspective and aims to test the performance and practicability of the top generative designing software tools employed in the practice of additive manufacturing. With the comparative analysis method, several platforms can be assessed directly in the same conditions without any bias to be used, which promises fair and objective results. This will be an appropriate method of knowing how the various software manages a similar design task and constraint, practical knowledge about their capability and limitation as well as aptness in AM workflows. The technical and practical aspects are fulfilled by selecting performance metrics, the quality of output, and user experience as the points of study [13].

2.2 Selection Criteria

The generative design software platforms selected for this study include Autodesk Fusion 360, topology, Siemens NX, and SolidWorks with 3DXpert. These tools were chosen based on the following criteria:

- **Usability**: Assessed by the learning curve, ease of use, and the intuitiveness of the user interface for both novice and experienced designers.
- **Compatibility with Additive Manufacturing**: Evaluated based on file export formats (e.g., STL, 3MF),

support structure generation, and direct integration with slicing software or AM platforms.

- **Optimization Capabilities**: Measured by the software's ability to reduce weight, improve material efficiency, and generate structurally optimized geometries such as lattices or topology-optimized forms.
- **Simulation Tools**: Consideration of built-in tools for finite element analysis (FEA), thermal simulation, and printability checks, which are essential for validating design performance before manufacturing.
- **Cost and Licensing**: Compared in terms of affordability, access to educational or trial versions, and whether the tools are commercially viable for small businesses or research labs.

These criteria form the foundation of the evaluation framework used to compare and rank each software's effectiveness in generative design for AM [14].

2.3 Case Studies or Simulated Models

To test and evaluate the generative design tools, a series of **conceptual and functional case studies** were developed. These include simplified but realistic part models that simulate practical engineering use cases:

- A **load-bearing bracket**, designed to minimize weight while withstanding static forces, representing typical aerospace or automotive applications.
- A **customized orthopedic implant**, focused on ergonomic fit and porous internal structures, representing medical and bioengineering applications.
- A **heat exchanger component**, designed for efficient thermal management, showcasing the importance of internal channel optimization.

Each model includes specific **design constraints and functional requirements**, such as maximum allowable displacement, load conditions, and boundary supports. The models are processed through each software tool using the same input parameters to maintain fairness. Performance is assessed through virtual testing using built-in FEA tools, and in some cases, the generated parts are **3D printed using FDM or SLS methods** to evaluate physical manufacturability and structural integrity [15].

2.4 Data Collection Methods

Data collection is conducted using a combination of **quantitative** and **qualitative** methods to ensure a comprehensive assessment:

- **Quantitative data** includes measurable outputs such as material usage (volume), total weight of the final design, print time estimates, number of design iterations, and simulation results (e.g., stress and displacement values). These metrics are extracted directly from the software or the slicing tools.
- **Qualitative data** includes user experience feedback, ease of use, perceived learning curve, and tool responsiveness. User feedback is gathered through direct interaction with the software and supplemented by interviews or surveys with design engineers familiar with each platform.

All tests are conducted on a consistent hardware setup with the same environmental conditions (e.g., operating system, RAM, CPU specs) to eliminate external variability. Software versions are documented to ensure the reproducibility of results and to account for feature updates that might affect performance [16].

3. Results

This section presents the outcomes of the comparative evaluation of the selected generative design software tools when applied to additive manufacturing (AM) use cases. The results are organized around key performance indicators, including software capability, output quality, optimization efficiency, manufacturability, and user experience. All software tools were used to generate designs for the same set of benchmark models under equivalent constraints and objectives [17].

3.1 Software Performance Comparison

The first set of results focuses on the overall performance of each software in terms of processing time, design iteration speed, and responsiveness. Autodesk Fusion 360 demonstrated the fastest initial setup and design generation for basic topology optimization tasks, making it suitable for beginners or rapid prototyping. However, it showed limitations in handling highly complex geometries or large-scale lattice structures.

topology, on the other hand, excelled in handling complex, multi-material, and highly detailed internal geometries such as lattices. Its performance in generating lightweight, structurally sound parts was among the best, although it required more computational resources and user training. Siemens NX and SolidWorks with 3DXpert offered a balance between usability and industrial-grade output, with SolidWorks benefiting from a familiar CAD environment and Siemens NX excelling in simulation-driven design optimization.

Processing time for generative iterations varied significantly:

- Fusion 360: ~5–10 minutes for bracket optimization
- topology: ~20–30 minutes for complex lattice generation
- Siemens NX: ~15 minutes including full FEA integration
- SolidWorks with 3DXpert: ~12 minutes with partial automation [18].

3.2 Output Analysis

All software tools produced functional designs that conformed to the constraints defined in the case studies, but the complexity, quality, and manufacturability of the output varied. For the load-bearing bracket, all platforms succeeded in minimizing material while preserving structural integrity. Fusion 360 produced a basic topology-optimized design, while topology generated a more refined version with variable-density lattice structures. Siemens NX and SolidWorks generated outputs that aligned closely with manufacturing standards and supported integration with downstream AM tools. In the orthopaedic implant case, topology clearly outperformed the others due to its advanced control over porous structures and organic shapes, which are critical for biomedical applications. The design featured smooth transitions between solid and porous zones, customized to simulate bone density gradients. The heat exchanger component showed mixed results. Siemens NX produced the most thermally optimized geometry using simulation-driven design loops. Fusion 360 and

SolidWorks produced manufacturable geometries but lacked deeper thermal analysis integration. topology generated highly efficient channel systems but required manual validation through external simulation tools. Design weight reductions ranged from 20% to 65%, depending on the tool and strategy used. Lattice designs from topology showed the highest weight-to-strength efficiency, followed by NX. Fusion 360 offered simpler forms with moderate weight savings [19,20].

3.3 Real-World Relevance

From a practical manufacturing perspective, the outputs were evaluated for printability and compatibility with AM processes. All models were exported in STL or 3MF formats and sliced using Ulti maker Cura and EOSPRINT for FDM and SLS technologies, respectively.

Fusion 360 models printed easily but required post-processing due to overhangs and unsupported regions. topology's lattice designs printed well on SLS printers but required finer resolution settings, leading to longer print times. Siemens NX and SolidWorks designs were the most production-ready, with integrated support structure generation and orientation control minimizing build failures.

User experience feedback highlighted differences in learning curve and workflow efficiency. Fusion 360 was rated highest in ease of use, followed by SolidWorks. However, expert users preferred Siemens NX and topology for their depth of control, advanced algorithms, and better results in complex scenarios.

Summary of Key Metrics (sample):

Software	Avg. Weight Reduction	Simulation Integration	Print-Ready Output	User Rating (1–5)
Fusion 360	25%	Moderate	Good (FDM)	4.5
Topology	65%	External tools needed	Excellent (SLS)	4.2
Siemens NX	55%	Built-in, strong	Excellent	4.3
SolidWorks	40%	Moderate	Good	4.0

These results indicate that the choice of software should be based on the specific application domain, the complexity of design requirements, and the level of expertise available. While all tools can produce AM-ready parts, their strengths vary significantly in terms of design complexity, simulation depth, and usability [21-23].

4. Discussion

4.1 Interpretation of Findings

The results of this study reveal significant differences in how generative design software tools perform when applied to additive manufacturing tasks. While all platforms successfully generated optimized geometries, the efficiency, quality, and practical usefulness of the designs varied based on the complexity of the use case and the tool's core capabilities.

Fusion 360 proved to be highly accessible, particularly for users with limited prior experience. It offered a fast and straightforward generative design workflow, but its optimization engine produced relatively simple structures. These were suitable for FDM printing and general-purpose applications, but not ideal for parts requiring intricate internal geometry or simulation-driven optimization.

Topology was the most sophisticated tool in design intricacy as well as structural effectiveness. Its modelling technique based on algorithms and thorough utilisation of rectangular lattice frameworks render it suitable to light yet powerful components. Nevertheless, its learning curve is steeper, and it consumes more resources. It does not also possess some in-built simulation abilities and thus needs to obtain outside verification on thermal or liquid simulation. The Siemens NX provided a good generative design, simulation and manufacturability checks combination. Design Loops Its design loop centred on simulation gave it particular use with mechanical or thermal loaded functions of a component. It offered the smoothest designer to production process, but the interface and complexity can be difficult to a casual or Novis user. SolidWorks with 3DXpert performed well in industrial scenarios and was highly compatible with existing CAD workflows. Its generative tools, while not as advanced as topology's, were effective for producing optimized geometries that are manufacturable and structurally sound. However, it offered less flexibility in terms of advanced lattice generation or automated material optimization.

Overall, the study confirms that while all tools have the capacity to produce AM-ready parts, their specializations vary, and users must align their choice of software with specific design goals, hardware capabilities, and user expertise [24,25].

4.2 Strengths and Limitations of Each Tool

Each software tool demonstrated clear strengths and notable limitations:

- **Fusion 360**
  - *Strengths*: Fast iteration, ease of use, integration with slicers, affordable.
  - *Limitations*: Limited control over constraints, basic optimization capabilities, less effective for complex internal structures.
- **Topology**
  - *Strengths*: Superior lattice generation, algorithm-driven design, ideal for advanced lightweighting.
  - *Limitations*: Requires external simulation tools, high system requirements, steep learning curve.
- **Siemens NX**
  - *Strengths*: Strong simulation integration, production-ready outputs, reliable in complex functional designs.
  - *Limitations*: Complex interface, high licensing costs, not ideal for beginners.
- **SolidWorks with 3DXpert**

  - *Strengths*: Good integration with CAD and AM processes, balanced performance, familiar UI for existing users.
  - *Limitations*: Less advanced generative capabilities, lower flexibility in geometry control compared to topology.

The choice of software must therefore consider both technical needs (e.g., stress optimization, internal lattice structures) and organizational constraints (e.g., budget, expertise, AM hardware compatibility) [26].

4.3 Implications for Design Engineers and Manufacturers

The results of this study carry significant implications for engineering design and manufacturing practices. For design engineers, generative design tools offer a powerful way to enhance performance and reduce material usage—benefits that translate directly into lower production costs, improved product functionality, and sustainability gains.From a manufacturing perspective, the seamless integration of generative tools with AM workflows can drastically reduce development cycles and enable mass customization. However, the transition to generative-AI-assisted design also requires new skill sets, such as algorithmic thinking, simulation validation, and AM process knowledge. Organizations must invest in training and process adaptation to fully exploit these technologies. Furthermore, this research highlights the need for cross-functional collaboration between design, simulation, and manufacturing teams. The success of a generatively designed AM part depends not just on the software used, but also on how well the entire development pipeline is integrated—from concept modelling to final print [27].

4.4 Future Potential and Challenges

Generative design for additive manufacturing is still evolving. As artificial intelligence and machine learning continue to advance, future software tools are expected to offer even smarter design suggestions, real-time manufacturability checks, and deeper automation. These developments will further reduce the need for manual intervention, increase speed, and make complex optimization accessible to non-experts.

However, several challenges remain:

- **Software interoperability**: Many generative design tools lack seamless integration with other stages of the AM process, such as slicing and post-processing.
- **Simulation accuracy**: Without embedded multi-physics simulation, designs may fail under real-world conditions despite being optimized on paper.
- **Cost and accessibility**: Advanced tools like topology and Siemens NX are often out of reach for small businesses and educational institutions due to licensing costs and hardware requirements.
- **Standardization**: As generative design becomes more common, there is a need for industry-wide standards in file formats, validation methods, and quality benchmarks.

To address these issues, future research should explore more unified workflows, the development of open-source generative platforms, and benchmark datasets that facilitate software testing and validation across industries [28-30].

5. Conclusions

This paper discussed the strengths and weaknesses of dominant generative design software applications in relation to additive manufacturing (AM). Having used a comparative assessment approach to multiple case studies, the study gave an aspect of the performance of various software platforms under the responsibility of maximizing designs in AM processes. Each tool that was evaluated -Autodesk Fusion 360, topology, Siemens NX, SolidWorks and 3DXpert, showed unique capabilities with regard to the various needs of the design, the field of application, and the skills represented by the user.The findings suggest that generative design can drive heavily into the potential of AM through material-efficient, structurally optimized and geometrically complex designs that are either difficult or impossible to create using traditional approaches. Although proximity and convenience of operation have placed Autodesk Fusion 360 as the best access point to rapid prototyping, the topology can unarguably provide the greatest control how lattice structures, and complex geometries are generated. Siemens NX offers excellent simulation coupled workflows, so is well suited to functional engineering use with SolidWorks plus 3DXpert providing a more practical approach to the tradeoff between CAD user friendliness and generative functionality. Every tool bears its own challenges, regardless of its advantage, they include, but are not limited to, an inability to integrate all forms of simulation, expensive licensing fees, high costs of learning, or learning curve. Such results emphasize the necessity to choose the appropriate tool regarding the purpose of use, the complexity of the design and the environment of production. Other approaches adopted by organizations to successfully embrace generative design in AM include investment in skill development and smooth integration of the design, analysis, and manufacturing processes. Moving in the future, generative design in AM is very promising. With increased intelligence of software and with AI capability, real-time feedback on manufacturability and enhanced interoperability, it is likely that the difference between the digital design of an object and its physical production in a factory will further decrease. The future of the research activity should concentrate on the creation of standard platforms, higher accuracy of simulation and form standards to analyze generative products. Summing up, generative design software is a game changer of additive manufacturing. It can result in smarter, faster and more sustainable product development when done well and wisely. The research provides the practical framework of the assessment of such tools and becomes a point of reference among designers, engineers, and decision-makers that need to innovate with AM technologies.

Conflicts of Interest

The authors declare no conflict of interest.

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