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GENERATIVE DESIGN: MANY TO ONE DESIGN SOLUTION

Mr. Indrajitsinh J. Jadeja, Ph.d Scholar, Gujarat Technological University, Chandkheda, Gandhinagar, Gujarat, India
Dr. Nirav P. Maniar, Associate Professor & Head, Mechanical Engineering Department, V.V.P Engineering College, Rajkot, Gujarat, India

Abstract
Traditional Design versus Generative Design is the point of discussion. Generative Design uses an integrated approach of mathematical optimization model, AI technology, cloud computing, CAD workstation and finite element analysis to offer many to one design solution for all engineering problems. The present volume of this research work explains the evolutionary approach of Generative design. It also discusses the steps of generative design and types of generative design methodology. Sample case study of machine structure design is also considered. A good number of title and research papers by renowned authors are referred while preparing this research work. This paper represents the classical example of how the present day most advanced technology of computer system, software and cloud computing can help designer to generate multiple solution and select optimum solution with minimum efforts and time.

Keywords: Computer Aided Design (CAD), Generative Design (GD), Cloud Computing, FEA, Many to one design

I. Introduction

Traditional design passes through two phases –
1) Iteration Phase and 2) Design to Production Phase.
Iteration phase follows following steps: Conceptual design based on customer requirements and preparation of various models under boundary conditions.
Design to Production Phase includes following steps: Checking the compatibility to produce prototype of all conceptual designs, Evaluation of manufacturing parameters to produce prototypes, validation and finally selection of one design for prototype making and manufacturing.
In comparison to traditional design approach, a new evolutionary approach is Generative Design approach, which uses a cloud computing method. This approach is many to one design solution for all engineering problems as it gives freedom to designers for selecting many design solutions for one engineering problem. GD helps to develop fast conceptual design due to the development of new edge technology in computer science and availability of more powerful computing software.
GD uses a mathematical optimization model to solve an engineering problem in combination with Finite Element Analysis to create an optimal part Geometries. It helps to create many conceptual models under boundary conditions such as materials, size, weight, strength, manufacturing methods and cost.

II. Literature Review

A good number of literature and titles written on the subject by renowned authors are referred to while designing this work.
Francesco Buonamici, Monica Carfagni, Rocco Furferi and Yary Volpe have taken into consideration the specific field of mechanical design and aims at describing available generative design solutions capable of dealing with structural optimization problems in an explorative design of generative design [1]. This research gives a brief idea of static structural design using generative approach and presented the case study of gripper arm of robot using AGD. Authors have also checked the manufacturing capability irrespective of model.
A generative design method for structural topology optimization via transformable triangular mesh (TTM) algorithm was applied in a structure to optimize the topology of structure under the constraint of

heat conduction parameter with comparison of numerical and practical approach by Baotong Li, Wenhao Tang & Senmao Ding and Jun Hong [2].
Deep Generative Design with Integration of Topology Optimization and Generative was developed by Sangeun Oh et al [3]. Case study of 2D wheel design with optimization and comparison of all generative design topology were presented in this research work.
Styliani Salta, Nikoloas and Miltiadis presented a case study in generative design and additive manufacturing in mass customization era using an adaptable emergency shelter [4]. Authors focused on structural and its aesthetic look with minimization of production cost by reducing the material usage and changing the topology design. The aim of this research work is not to provide a standardized design outcome, but to create a methodology which later in time may set up a dynamic solution data-base for shelter designs. Authors also proposed a different result of generative design and created Shape Grammar Library (SGL).
The minimum material requirement for supporting structure using SIMP & BESO for topology optimization to solve problem was proposed by Evangelos Tyflopoulos et al. [5]. Authors presented state of the art of generative design and topology optimization and potential research needs. Authors also compared the different topology optimization approach like SIMP, RAMP, BESO, NOM, DDP & XFEM.
Emmanuel Francalanza, Alec Fenech and Paul Cutajar prepared different robotic manipulator designs using generative design approach and developed one prototype using additive manufacturing method [6]. Results of research work optimized weight, time and cost using generative design approach.
In research work on Topology optimization for heat conduction using generative design algorithms, Danny J. Lohan, Ercan M. Dede and James T. Allison presented a new approach to topological design for steady-state heat conduction [7]. The method capitalizes on the use of a generative algorithm to represent topology, resulting in a decrease in the number of variables in the design description. The Space Colonization Algorithm, which can generate similar topological patterns, is selected for in-depth investigation. A genetic algorithm drives generation of design candidates, providing a highly diversified search of the target design space. Finally, several synthesized optimal designs for steady-state heat conduction, derived using the described algorithms, are compared using commercial finite element software.
In an article on Load-Adapted Design of Generative Manufactured Lattice Structures, Gunther Reinhart and Stefan Teufelhart explained how the change of the lattice topology structure using generative design [8]. Authors presented their experimental study on beam and redesign the topology of beam using torque and force constrained. Authors also further expanded studied on shaft and achieved conclusive parametric solution.
Sivam Krish presented built a genotype of the design within a history based parametric CAD system [9]. The generated designs are then filtered through various constraint envelopes representing geometric viability, manufacturability, cost and other performance related constraints. Author also presented a brief idea of Generative design Process.
The following section explains steps in Generative design approach.

III. Steps of Generative Design

Step 1: Enter Design Goals & Constrained in Generative Design Software
In this stage, designers enters goals to create a design like defining a constraint, set some preserved area in that design which can be fixed for product like holes, bores or fastening area that cannot be rearranged by computer and hence become fixed.
Step 2: Computer Generates a range of design options.
The role of computers using a cloud computing technology and CAD workstation are introduced in this stage, which generates multiple option designs.
Step 3: Study design and adjust goal/constraints, computer regenerates, choose best design to iterate and optimize.

In this stage, called a selection stage, the designer studies the various iteration design generated by CAD system in stage-2 & finally select one design and optimize the design as per close constraints like load, cost, material, weight etc.
Step 4: Choose a manufacturing method and send for production.
The designer chooses a proper manufacturing method to prepare prototype by selecting which has been selected in stage 3. Mainly, the designer chooses an additive manufacturing or 3-D printing process to develop prototype.
Different types of Generative Design Methodology are explained in the next section**.**

IV. Types of Generative Design Methodology

The following are the types of Generative Design Methodology.
1. Shape Grammar method
2. Parametric CAD
3. Deep Learning on Binary Image
4. Termite Nest & Class A surface
5. L- System

1. Shape Grammar method

A finite set of shapes with transformation rules are applied step-by-step to an initial shape in order to generate designs in this method. It is spatial, rather than symbolic. Applying shape rules generates designs, and the rules themselves describe the generated designs as a design grammar. Due to this, shape grammars are used both generatively and as tools for analysis to formalize existing designs.

2. Parametric CAD

Feature-based parametric modeling describes solid models symbolically in terms of a set of parameters and their relations such that changes in one parameter will update the whole model.
Parametric models are more familiar to designers and many existing workflows & software including simulation and analysis use them. However, parametric representations are not inherently generative and must be adapted to serve as such.
Algorithms must be developed to operate directly on the parameters of the model. Conversion from other generative representations such as shape grammars is possible but not always straightforward.

3. Deep Learning on Binary Image

Deep learning techniques is a combination of Topology Optimization and Generative Adversarial Networks (GANs). It was used to generate multiple designs satisfying both engineering and aesthetic requirements.
The aesthetic filtering carried out by the GANs was based on the assumption that existing designs are more aesthetically pleasing than arbitrary Topology Optimization output. To implement this assumption, a library of existing designs and a distance function were used. This integrated approach was used for generating multiple options of design.

4. Termite Nest & Class A surface

The major focus of this method is DFM concerns. The intention was to simultaneously design, structurally optimize and evaluate the additive manufacturability of the part. The product form was represented by voxels and termites deposited material according to functional constraints and design objectives. An FEA solver was used to evaluate structural integrity & manufacturability and was assessed based on support material and tool accessibility.

5. L-System.

L-systems are also production systems that can be used to generate designs by recursively rewriting strings of symbols.

They differ from SGs in that they operate on strings that represent a design symbolically rather than spatially.

V. Sample Case Study – Machine Structure Design

5.1 Classification of Machine Structure

Machine structure can be classified into following categories:
Category 1: An element upon which various sub-assemblies Mounted.
Category 2: An element consists of a part used for supporting and moving work piece.
Category 3: An element consist of box type housing in which individual parts are assembled.

5.2 Criteria for Machine Structure Design

Accuracy: The initial geometric accuracy of the structure should be maintained for whole life of machine tool
Safe Life Design: The shape and size of structure should not only provide safe operation and maintenance of the machine tool but also ensure that working stresses and deformation should not exceed specific limits.
Design for Assembly: All mating surfaces of the structure should be machined with a high degree of accuracy to provide the desired geometrical accuracy.

5.3 Design Criteria for Machine Structure

Consider structure as simply supported beam,
Factor affecting the design for machine structure is

1. The maximum bending moment
2. Identify the neutral axis of section
3. Moment of inertial of section
4. Deflection of beam

If point load is considered at Centre, normal stress is given by

$$\sigma_{max} = (B_{max} * D_{max})/I$$

Where
B = Breadth,
D = Depth and
I = Moment of Inertia

Minimum volume and maximum volume required for permissible deflection of beam is calculated after calculating normal stress.

5.4 Consideration of parts while Designing Machine Structure

5.4.1 Design of Bed

Bed is designed considering following criteria,

- Wall arrangement
- Top closed Profile
- Open top profile

Bed on legs without stiffening diagonal wall and with stiffening wall.
For the minimizing the weight of a Bed, the following design criteria should be considered.

Maximum Deflection of the Beam (Y_{max})
Type of material - No of Stiffener and its arrangement in Bed

5.4.2 Design of Column

Column consists of a spindle head in machine tool with fixed bed.
The principle design requirements of columns are high static and dynamic stiffness. These properties are achieved by proper selection of the column material and its cross-section.
It is designed as per the commonly used section with or without stiffeners.
Square box & Regular Box type section with vertical ribs or circular section is used.

5.4.3 Design of Housing

Housing may be split or solid. Solid housings are used in small and medium sized machine tools. Split housings are easier to assemble but stiffness is less as compared to solid ones.
Housing type structures are designed for stiffness. The stiffness is determined by determining the displacement. This displacement is due to a force acting normally to the wall at the same point.
Next section presents the conclusion.

VI. Conclusion

In traditional design, designer can use a computing technology to generate one model at a time and a workstation as a passive machine. In the modern era, Design engineers use cloud computing technology to concrete the design and build up the Generative Design.
In the old era, designers work on the fundamental of one designer + one computer = limited design option. While in the modern era, designer uses AI technology and cloud computing technology, the equation for designer is changed like One human + AI + Unlimited Cloud computing Power = many design option.
Conclusive evidence of GD is helpful in the area of product design, Assembly modelling, Product development, Geometric modelling, Analysis (like FEA, Structural analysis).

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