

A study of Generative Design as a practical
aid to the design engineer

Generative Design: a solution or starting point

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Contents

Introduction	2
Design objectives	2
3D modelling	3
Regenerative modelling	6
Discussion.....	10
Load limitations.....	10
Idealised manufacturing and material performance	10
Limited to AM at this stage	10
Conclusion.....	10
Reference list	11

Introduction

A 2D design is ported using Fusion360 Computer Aided Design (CAD) software package to produce a 3-dimension model on which an AI based Generative Design add-on module can be applied, with desired variables such as physical location restraints and static loading sets may be applied (www.autodesk.co.uk, 2020).

Generative design (Ntintakis and Stavroulakis, 2020) empowers a user to explore multiple possible models for specific or a range of manufacturing methods and compare the relative advantages across a range of relevant parameters including material consumption, part volume, part mass, stress, displacement, safety factor and manufacturing guide costs via third party manufacturing bureaus.

In the literature Generative Design is frequently directed at production utilising Additive Manufacturing methodologies (GDfAM).

The association with the reactive and sympathetic development of nature's structure is striking. (Dhokia et al., 2017) details a case study on an algorithm inspired by termite nest building to achieve structural integrity with volume reduction, and how these fit with AM technologies. Wang et al., 2021, present tree like structures which are not only effective in their applications but also aesthetically pleasing and desirable in living environments. Bioinspiration in structural supports (Zhang et al., 2020) and in the building industry in general is now becoming at least a starting point for architects and engineers (Pasetti et al., 2018) The application of GD in the building world gaining credibility.

Where a rapid minimal solution is desirable GD can provide design starting points, the Covid 19 pandemic of 2020 onward required a low material volume solution, the pandemic itself constrained the availability of raw materials, door handle adapter to minimise human hand touch and virus transfer was rapidly designed using GD, meeting the material usage restriction (De Crescenzi et al., 2022)

Numerous applications for GD exist in the transport and especially automotive industry, given the need to lowering the mass of componentry in electric vehicles (Briard et al., 2020), (Markovits and Szederkényi, 2022). Autonomous vehicles also benefit from minimisation of mass to aid flight endurance from constrained energy sources and optimise performance such as a nose cone design for a UAV (Zaimis et al., 2021), which was multi-axis CNC'd as opposed to the more frequent AM manufacture.

Design objectives

As the theme of the study is to produce parts using additive manufacturing materials processed by three commercial 3D printers were selected with broadly similar polyamide 12 build material. One material contained strengthening additives as short carbon fibres (CF).

- EOS P 3D printer series; Selective Laser Sintering (SLS) – PA12 CF
- FormLabs Fuse1- SLS -PA12
- HP Jet Fusion 580 - MultiJet Fusion (MJF) -HD 3D HR CB PA12

The desired objectives of minimising mass and specifying a default target safety factor of 2 were chosen. Mission critical applications often require a much higher safety factor floor.

3D modelling

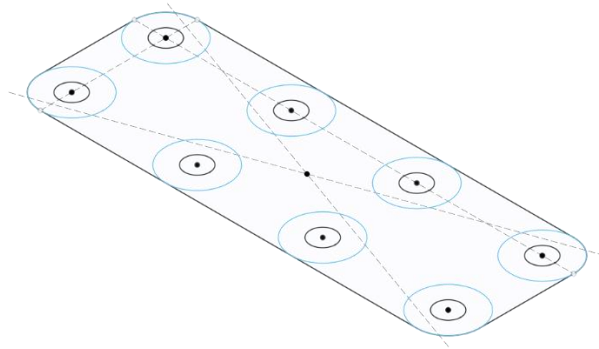


Fig. 1

Fig. 1 Example 1, selected from a set of proposed drawing and ported for further modelling.

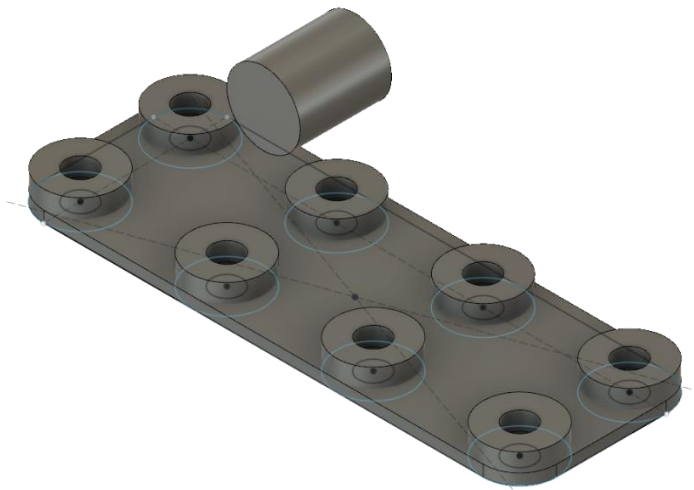


Fig. 2

Fig. 2 A degree of creativity was allowed and hence the eight circular features were extruded to act as load bearers and a cylindrical axel was added to perform the role of a fixed structure to effectively secure the loads from above.

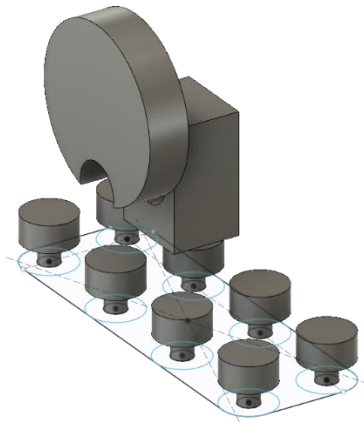


Fig.3

Fig.3 An additional set of keep-out features were generated to constrain the generative aspect of the module in space, specifically to allow the use of short bolts with access for an Allen key to tighten a load securing fixture and arbitrarily about the axle, solely to explore how the module might grow the part while restricting some rotational movement and permitting access to the axle length, for mounting purposes.

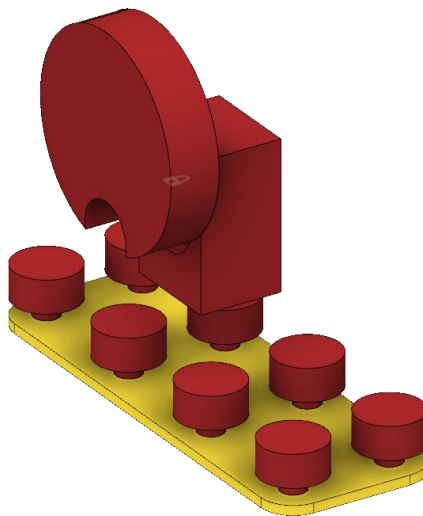


Fig. 4

Fig. 4 illustrates the obstacle geometry selected in red and the original base (to be ignored in the modelling)

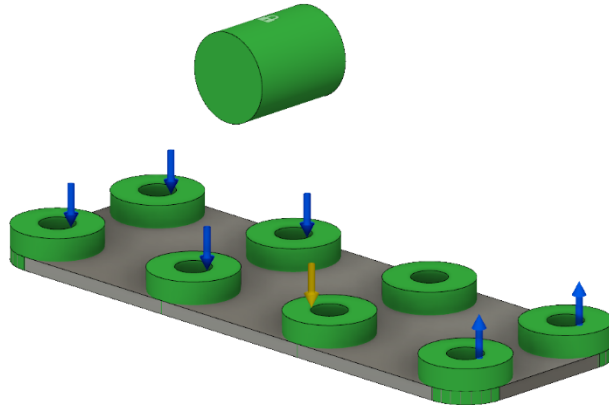


Fig. 5

Fig. 5 illustrates the preserve geometry selected in green and the original base (to be ignored in the modelling). Forces are applied differentially to each extrusion (directionally), with none being applied to two locations. Gravity (default at sea level) is also applied to the model.

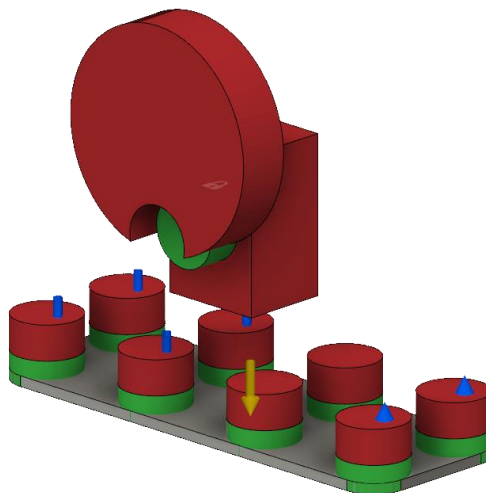


Fig. 6

Fig. 6 shows the configured study readied for modelling with the axel fixed on an axis along its length.

Regenerative modelling

A set of forces were detailed under the 'load case' setting in study 1, and a clone, study 2 had the loading at each point multiplied by a factor of 10, allowing observation of adaptations generated under otherwise similar study conditions.

Additive manufacturing designated design objectives

- three relatively comparable PA12 materials for additive manufacture,
- a safety factor of 2
- minimisation of mass

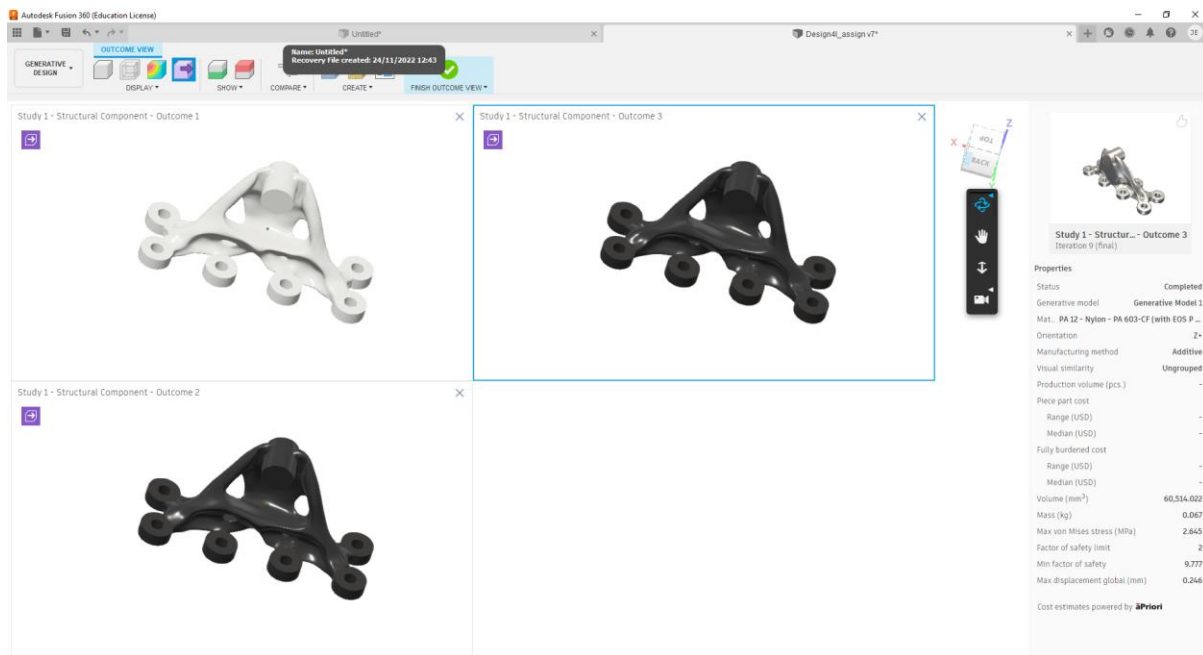


Fig. 7

Fig. 7 Study 1 generated 3 similar models. To assist rapid comparative investigation, select parameters were chosen as axis variables in graphical visuals using a chart display mode.

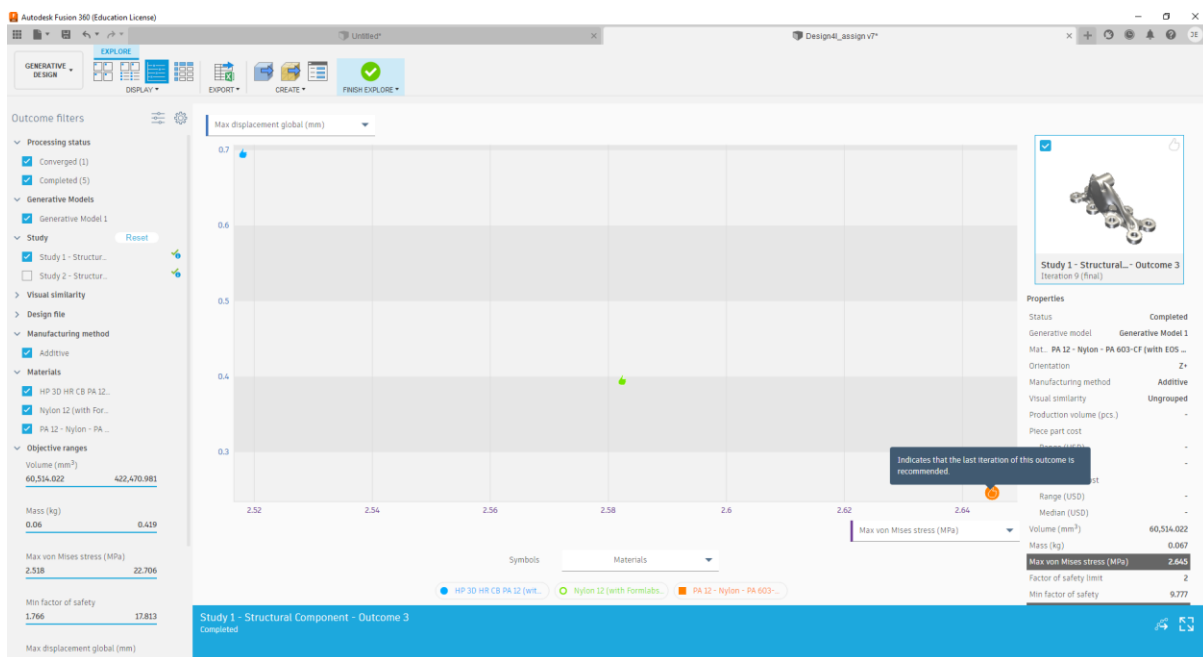


Fig.6 illustrates outcome 3 although being highest in a small range of Von Misse stresses, is the lowest manufacturing mass, and is also illustrated as having the lowest loaded deflection, see Fig. 7

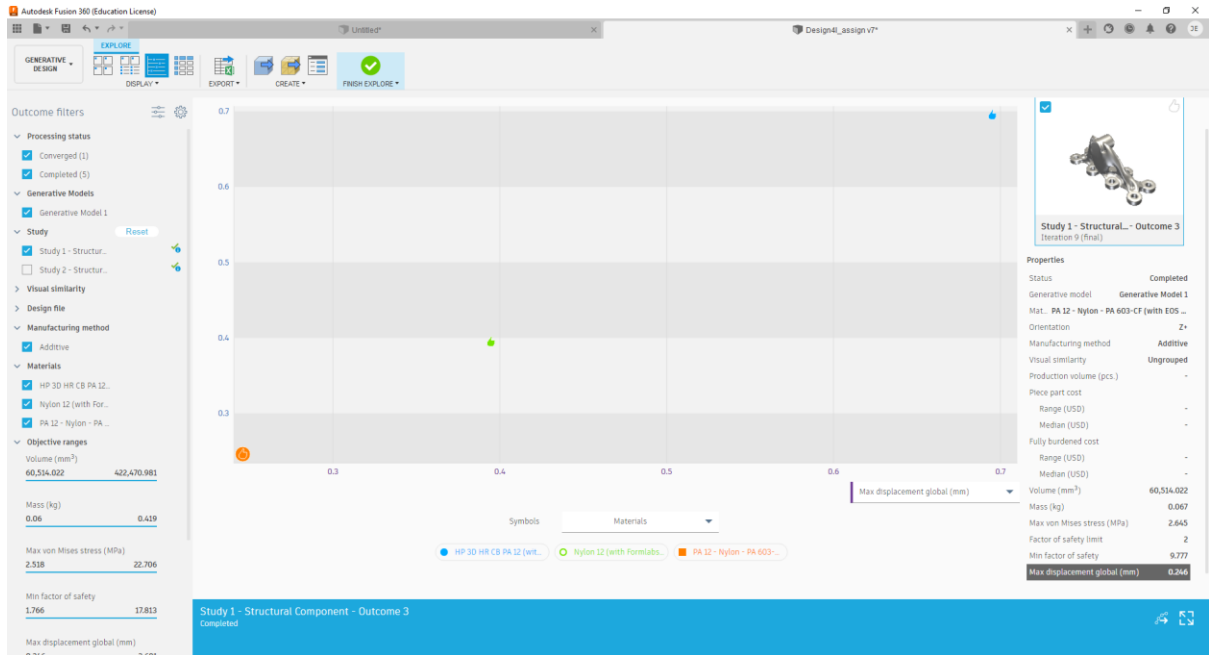


Fig. 7

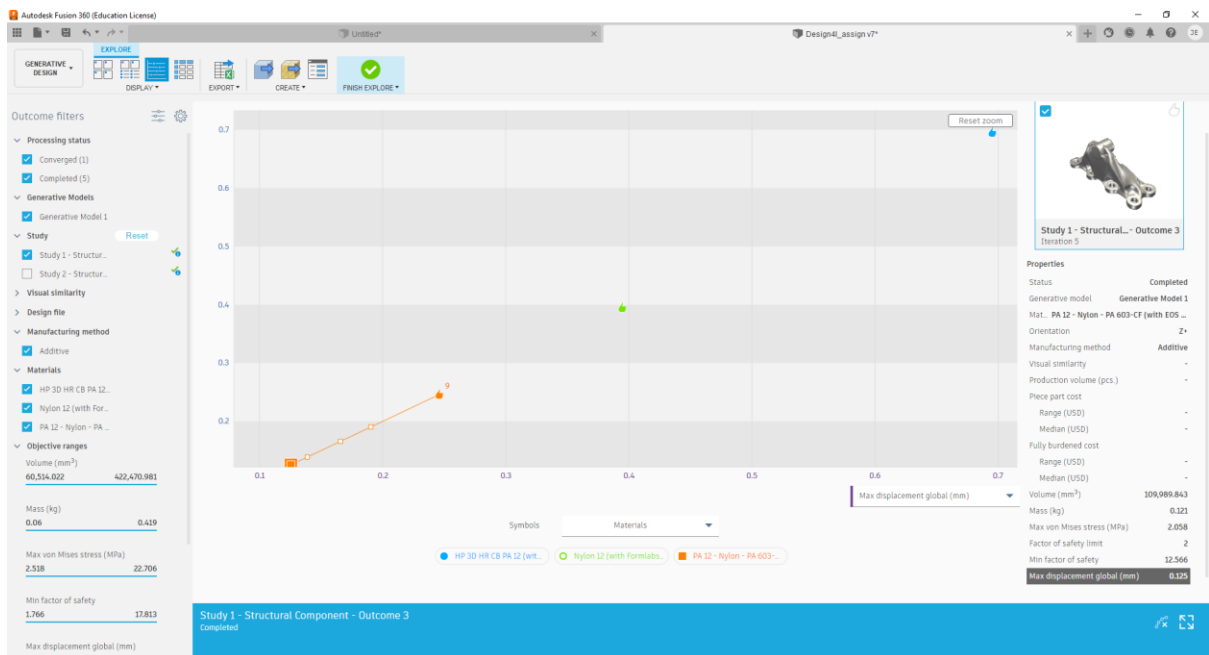


Fig. 8

Fig. 8 The user may also review model performance at previous iterative stages of the model development, it is observed as the model evolves to reduce mass, the stiffness and max displacement increases.

None of the three outcomes converged on the selected objective parameter, namely the safety factor, inspection of the stress maps overlayed showed all three were significantly over engineered for the task, in spite of the mass for each outcome being in the order of 60g to 67g, with differentially loaded points totalling in excess of 80 Newtons force transferred to the fixed axle element.

Study 2 showed quite different outcomes with universally increased loading on the structure and the three differing materials and additive manufacturing strategies (and related build materials).

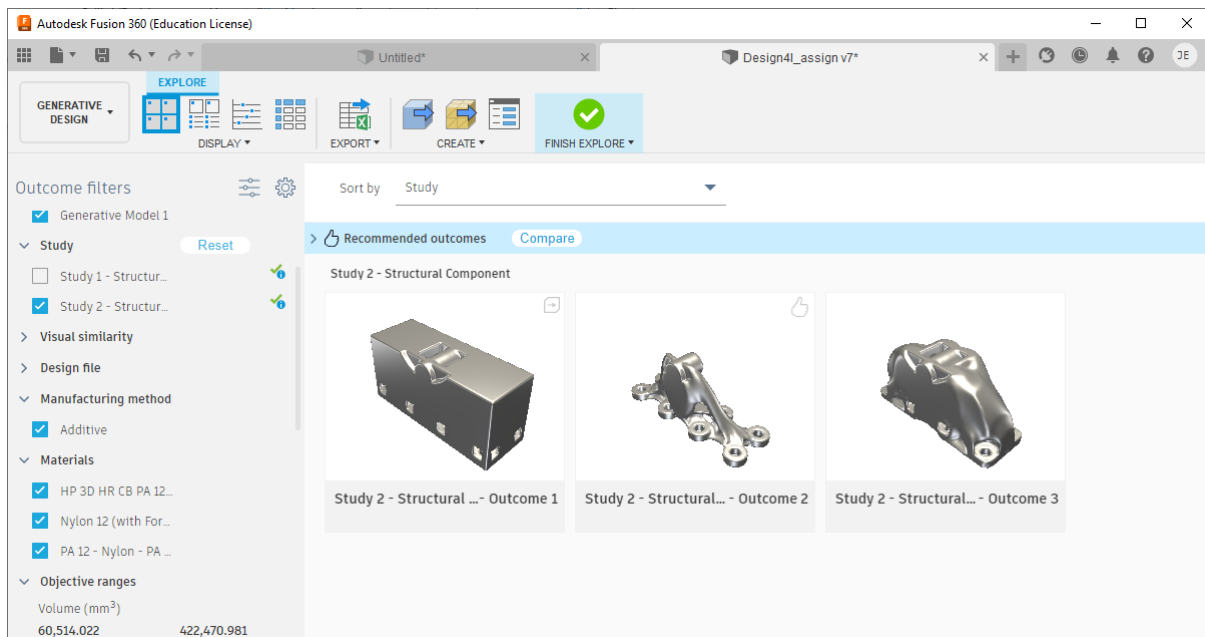


Fig. 9

Fig. 9, Outcome 3 fully converged and met the safety factor objective of 2 exactly, however the mass of 321g was approximately 20 times larger than non converged outcome 2 of mass 67g, which managed a safety factor of just over 2. Outcome 1, MJF, failed to achieve the safety ceiling with the FEA showing unacceptable stress on multiple faces as shown in Fig. 10.

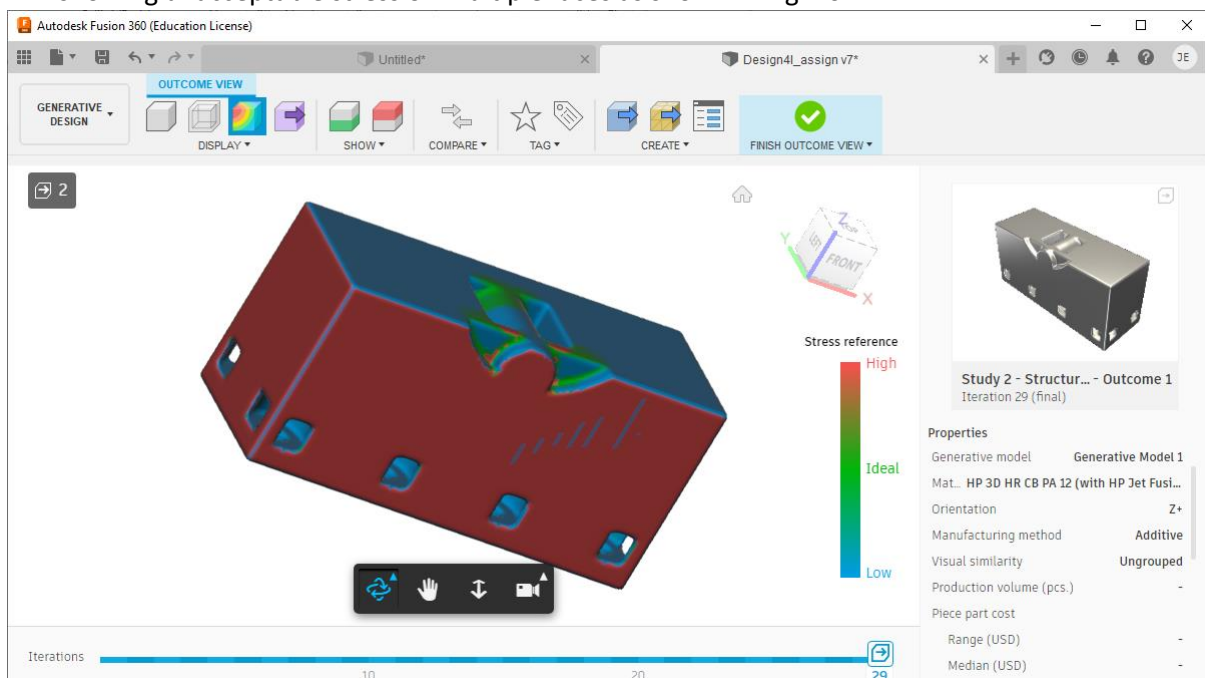


Fig. 10

Discussion

Load limitations

static loads only are often poorly correlated to real world applications

Idealised manufacturing and material performance

In many additive manufacturing processes, the build is far from perfect, SLS materials are often virgin/reclaim mixtures, are subject to manufacturing and storage fluctuations, voids are unavoidable during the build, and operator/equipment performance imperfect. Modelling of load and stress bearing characteristics cannot accommodate the multiple unknown deviations from the ideal.

Limited to AM at this stage

It is difficult to measure how practical Generative AI can be as an end-to-end design solution. The studies have created interesting forms which are strongly bio-mimicking, but intuitively conflict. Study 1 outcome 3 is substantially similar in form and mass to Study 2 outcome 2 (both SLS AM), despite a relative ten-fold loading. The higher loaded study did have a much lower but acceptable calculated safety factor. The converged Study 2 outcome however was of significantly larger mass, an important consideration in small to medium scale AM strategies, wherein this AI powered design tool would appear to have a solid investigatory role.

Conclusion

The organic structures generated would largely be difficult to machine given the complexity of tooling access and moving tool clearance. Moulding and traditional machining of organic forms encounter technical difficulties which are broadly unaccounted for in the generative module configurations and at this stage of the AI module evolution, it would seem immature and lacking application.

AM however is practical to some extent as thermal flow (moulding) and tool accommodation no longer apply. Although mass, volume, stress, safety factors and deflection under load are calculated, the idealised AI generative algorithms cannot take account of the numerous deviations from that ideal in at least build efficacy, material non-uniformity and build environment, and therefore caution should be exercised in reliance on the design proposals without secondary evaluations including real world empirical testing. Generative design however does enable the design with some low effort design alternatives, the nature inspired forms which may be embedded in the AI algorithms may also prove to be as effective as nature itself in active adaptation to stress to achieve minimum resource allocation in its environmental challenges.

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