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# Are generative design tools creative? A characterisation of tools throughout the design process

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**Abstract**

Generative design is now a core capability of today's CAD systems enabling broader exploration of the design space. This paper presents a desktop review of 15 tools with the aim of characterising where the tools are used in the design process and to what extent they can be considered creative.The results showed that, despite their increasing capabilities, GD tools are unable to exhibit all phases of creativity and cannot be applied in all stages of the design process. This highlights the criticality of the human in design providing opportunities for GD to augment designer creativity.

*Keywords: creative process, creativity, design process, generative AI, generative design*

## 1. Introduction

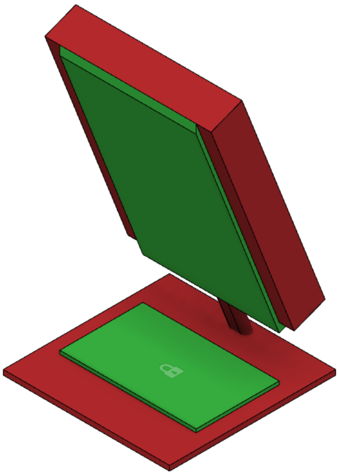
Generative design (GD) systems were first conceptualised by Mitchell (1975) for architectural design. In the following two decades very few publications gave the topic any further attention (Caetano, Santos and Leitão, 2020). In recent years, development has returned to the field with an increasing publication rate - 288 published with the phrase 'generative design' in 2022, up from 80 in 2017 (Scopus, 2023) - and the release of several tools for both academia and industry such as Fusion 360 GD suite (AutoDesk, 2023) and CATIA GD Engineering (Caetano, Santos and Leitão, 2020; Dassault Systemes, 2020).

With increased computing capability, in particular the development of cloud computing services, and the maturation of Additive Manufacturing (AM) capable of constructing complex geometries, GD tools are becoming increasingly feasible for practical use in engineering. Fusion 360's GD tool, which can perform either structural or fluid path studies and is aimed specifically at mechanical engineering applications, is a good example of this. An example of the tool's use for generation of a mobile phone stand structure can be seen below in Figure 1a and Figure 1b.

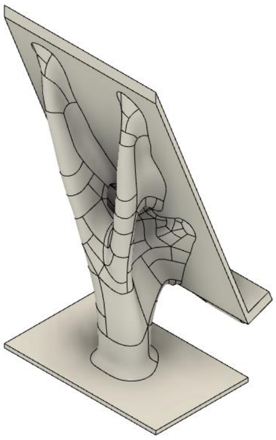
Released in 2023 OpenAI's DALL-E 3 and similar generative AI tools also demonstrate capability to generate designs (Bing, 2023). DALL-E 3 can generate images directly from text prompts, an example of which can be seen in a design generated with the prompt 'mobile phone stand', shown in Figure 1c[1].

Engineering GD tools are principally utilised for their ability to widen the search into different solution types. This 'design space exploration' increases the ability to present new and high-performing solutions to a design problem. GD tools facilitate this design exploration in several ways. Many of the specialist engineering GD tools are built upon an optimisation framework that enable them to explore the design space as they search for the 'best performing' solution.

[1] As an aside, note how the interpretation of 'mobile' has been applied to the 'stand' as well as the 'phone'.



(a) Mobile phone stand generative design study geometry setup with Fusion 360



(b) Result of Fusion 360 generative design study

(c) A design created using DALL-E 3 with the prompt 'mobile phone stand'

**Figure 1. Examples showing usage of generative design tools**

GD tools also facilitate exploration through their lack of bias. When humans tackle design problems they necessarily begin with preconceived notions of what the solution may look like due to their upbringing and cultural drives (Sawyer, 2006). Specialist engineering GD tools do not have these constraints[2] and instead are constrained by the characteristics of the output of their algorithm.

Finally, the ability of GD tools to speed-up design iterations can also act to increase the design space search as it enables designers to consider a greater quantity of options. Generative design tools can create several highly developed solutions within hours or minutes. This capability allows designers to compress the iteration period and focus time elsewhere.

As the use of GD tools becomes widespread, several aspects of how they can contribute to a designer's workflow remains unclear. First, where can these tools be utilised within the design process? Experienced designers develop procedures and habits as they tackle problems. Therefore, if they are to adopt GD tools as part of their workflow, they require the knowledge of exactly how and where the tools can add value. This characterisation forms part of this paper's contribution.

Second, can GD tools be considered creative? During progression through the design process there are multiple instances where creative input is required to ensure a workable solution (Cross, 1982; Howard, Culley and Dekoninck, 2007). As such, it is necessary to understand what aspects (if any) of creativity these tools display so that designers can decide how to utilise them most effectively. The authors can find no other work that focus upon these areas at the time of writing. This paper continues by examining the related work on GD tools, the design process and creativity (Section 2). This is followed by an explanation of the desktop review method used to evaluate the tools (Section 3). Next, a mapping of the tools with respect to the design process and the creativity aspects that they display is presented (Section 4). The implications of the mappings are discussed (Section 5). The paper then concludes with the main findings from the investigation (Section 6).

## 2. Related work

This section provides the chosen definition of GD and justification for the use of design and creativity process models. Process models are considered from the literature and the most appropriate is selected.

[2] This is unlikely to be true for tools that have been trained such as DALL-E 3 as they are likely to have absorbed human bias during their 'learning' process.



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## 2.1. Generative design tools

There is not an agreed-upon definition of GD. For the purposes of this investigation, the definition presented by Caetano et al. (2020) will be used: "GD is a [computational] design approach that uses algorithms to generate designs", where generative is the "capacity to produce or create something". Other definitions such as those given by AutoDesk (2023), Bernal et al. (2015) and Oxman (2008), make further distinctions between algorithms based upon the required input and number of generated outputs. This study, however, will not consider these distinctions as they narrow the scope of the investigation by limiting the number of eligible tools. Functionally, the implication is that for the purposes of this investigation, no categorical distinction is made between topology optimisation and GD.

In engineering a 'design' is a blueprint that defines a machine system through some means. The stage of the design process likely dictates the form this design takes, with earlier stages relying on abstract natural language and later stages focussed upon less ambiguous dimensioned drawings.

Several methods are used to achieve GD capability. Traditionally, these have mainly been L-systems, Cellular Automata, Genetic Algorithms, Shape Grammars and Evolutionary Design (Caldas, 2008; Singh and Gu, 2012; Abdelmohsen, 2013; Caetano, Santos and Leitão, 2020; Starodubcev et al., 2023). Fundamentally, with regards to application to structural generation, these methods primarily operate by adding and removing cells of a meshed domain in accordance to defined stress criteria. The consideration that an AI tool such as DALL-E 3 can operate as generative design systems adds additional methods to this list. Generative AI tools function by using various types of algorithmic Artificial Neural Networks, maintaining consistency with the chosen GD definition (Ramesh et al., 2022).

## 2.2. The design process

At present, GD is most often discussed in the context of structural optimisation (e.g. Díaz et al., 2021; Wang, Zhang and Bernard, 2021; Barda et al., 2023). This necessitates that the discussion focuses upon the finalisation of the design process. It is generally agreed, however, that creativity is most obviously displayed earlier in the design process (Snider, 2014; Wodehouse and Casakin, 2022). This study therefore endeavoured to include and characterise tools throughout the design process to create a comprehensive view of the level of creativity of all GD tools.

To situate the GD tools within the engineering design process, requirements were placed upon the model used in the study. The model needed to reflect development from idea to artefact, be applicable to the design of machine systems, and balance generalisation with fidelity within the design stages. The Design Council (2006) double-diamond framework, Gero and Kannengiesser (2004) FBS framework and Pahl and Beitz (2007) were compared to determine which was most appropriate given these requirements.

The Pahl and Beitz (2007) model was found to be most applicable. It centres around the four stages of Task Clarification, Concept, Embodiment and Detail which broadly explain how designers can progress from their initial ideas through to a complete solution. During Task Clarification the designer defines the problem by considering objectives, constraints, stakeholder requirements and feasibility. In the Concept stage designers search for solution principles that can tackle the problem. In the Embodiment stage this solution principle is refined into an architecture. Last, in the Detail stage the architecture is finalised into a specific structure that performs suitably. This model was considered appropriate due to its 4-stage fidelity within the problem-solving process and common usage describing technical and machine system design.

In addition to adopting a process model, it is necessary to define the interpretation of some terms for the purpose of the study. Aeroplane landing gear will be used as an example case. The 'problem definition' considers the need for a cushioning system that dampens landing sufficiently to prevent damage to the aeroplane and its occupants whilst allowing a low friction interface with the ground for quick take-offs. A 'solution principle' is the type of mechanism settled upon following the concept stage; this might be wheels as opposed to landing skids. The 'architecture' is the configuration achieved; the wheels are arranged into three sets, one under the nose and one under each wing. The 'final structure' is the complete design; each set will contain two wheels of 0.5m diameter. In the Concept through to Detail stages the designs can be represented in a variety of ways - from natural language to dimensioned


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drawings - with the abstraction decreasing and precision increasing as the process advances as discussed above in Section 2.1.

### 2.3. Creativity

Creativity is regarded as an essential attribute for a successful designer, allowing them to tackle problems in a variety of new, interesting, and applicable ways (Askland, Ostwald and Williams, 2010; Wodehouse and Casakin, 2022). As such, if GD tools are to increasingly complement human designers in their work, a gauge of their creative ability is necessary. Sarkar and Chakrabarti (2007) and Sawyer (2006) explain that the two necessary conditions for creativity are novelty and appropriateness. However, satisfying these two conditions is not straightforward. It requires both real world evaluation and either re-purposing of existing technology or invention of new technology (Sawyer, 2006).

The subjective nature of creativity makes direct and quantitative measurement impossible when considering a range of problems due to its cultural and experiential influences (Amabile, 1996; Sawyer, 2006). An analogue for creativity measurement was therefore employed. To do this, a gauge of creativity was taken by mapping the tools' processes to a model of the creative process. This allowed insight into the level of creativity of the tools whilst also serving as a guide for the abilities that the tools would need to gain to be considered creative.

For their study into the intersection between the design and creative processes, Howard et al. (2007) compare nineteen creative process models and suggest common phases that most of the models include. These phases were chosen as an appropriate creative process model for use in this paper due to the rigorousness of Howard's study and its wide acceptance: it has been cited 90 times for use in other studies. Howard finds that the phases of the creative process are:

- Analysis - Problem interpretation
- Generation - Incubation and synthesis of ideas (preferably many)
- Evaluation - Selection of the most appropriate solution from all the available options
- Implementation - The process of maturing the solution to use/ application via commit, manufacture or deployment

Howard's inclusion of Analysis and Evaluation within the model serve to ensure that only intentional design serves as creativity. Without recognition of these phases creativity can be identified in random physical processes: is a glacier creative in its carving of a valley?

## 3. Methodology

The Methodology section begins by explaining the desktop review method used to characterise the design tools. The placement of tools within the design and creative processes is then demonstrated with examples.

### 3.1. Desktop review

To map the processes exhibited by the tools against the chosen design process and creative process models, a desktop review was conducted of each of the tools. For this, an initial list of 28 tools was found from an internet search of design tools beginning with the terms: 'generative design tools' and 'engineering generative design tools'. These 28 tools form a non-exhaustive list. Further investigation narrowed the list to 15 tools that comprised sufficient related information for the authors to make a full characterisation as outlined in Section 3.2 and 3.3. The desktop review was then conducted for these 15 tools to assess their inputs, operation, and outputs. To do this, academic literature, promotional material, and case studies were considered amongst other sources. This process is illustrated in Figure 2.

The 15 tools selected for review were: *TRIZ* (Gadd, 2011; Petrov, 2023), *Functional Analysis* (Little, Wood and McAdams, 1997), *Brainstorming* (Putman and Paulus, 2009), ChatGPT (Filippi, 2023), *Morphological Analysis* (Arciszewski, 2018), DALL-E (Bing, 2023; Brisco, Hay and Dhami, 2023), CATIA GDE (Dassault Systemes, 2020), Inspire (Lim and Wong, 2018), Ansys (Ansys, 2021), Abaqus (Johnsen, 2013), Sulis (Altair, 2023; Das et al., 2023), Siemens NX (Menninger, Berroth and Jacobs, 2022; Siemens, 2023a), AutoDesk Fusion 360 (AutoDesk, 2023), Simulink (MathWorks, 2023) and Amesim (Siemens, 2023b). The four italicised early-stage design tools in this list are not computational



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methods. Whilst computational tools exist to aid in the application of these tools, they are fundamentally applied by human designers. As such these tools do not fit satisfy our definition for GD. It was decided that these tools should be included in the review as they provide a comparison against the generative AI tools and aid in understanding of the methodology.

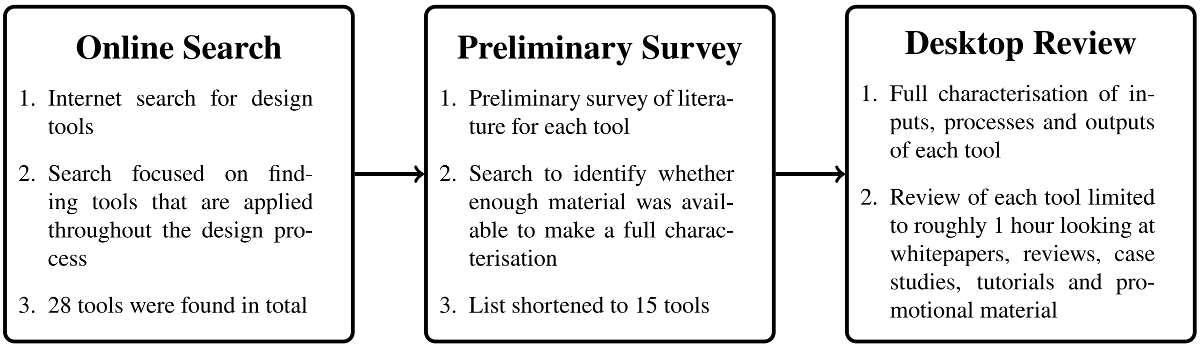


**Figure 2. The desktop review process**

## 3.2. Design process characterisation

The input and output of each tool was used to characterise the design stage that the tools operate within. Table 1 demonstrates the inputs and outputs used to classify each tool as operating in a specific design stage. Simcenter's Amesim is a good example of how these inputs and outputs were used to characterise and map the tool against the design process (Siemens, 2023b). Amesim is a design tool that aims to aid the design of multi-physics mechatronic systems. Designers interface with Amesim's tools and solvers using block diagrams where components are selected from a library. Multi-physics systems can be built by assembling these components. Here the input of the generative tool is the architecture established by component selection and connection by the human designer. The generative algorithm aims to search and optimise component parameters. The output is a specific parameter set that gives the design a finalised structure. The generative capability of Amesim therefore sits within the Detail design stage as it takes an architecture as input and outputs a finalised structure.

**Table 1. Attributes used to characterise the tools within the design process**

| | Input | Output |
|---|---|---|
| **Task Clarification** | Mess or Obstacle | Defined problem |
| **Concept** | Problem statement | Solution principle |
| **Embodiment** | Solution principle | Architecture |
| **Detail** | Architecture | Finalised structure |

## 3.3. Creative process characterisation

The tools' inputs, algorithms and outputs were also used to characterise their capability with respect to Howard's phases of creativity. The inputs and algorithms required by the Analysis phase are unclear; this will be discussed further in Section 5. The output of the Analysis phase is a defined problem.
The Generation phase of creativity can occur at all stages of the design process (Howard, Culley and Dekoninck, 2007). The input to the Generation phase can therefore be in the form of an obstacle, problem statement, solution principle or architecture, as shown in Table 1. A tool that supports Generation should create and synthesise designs, conforming to the earlier definition of GD. The tool should then output a set of solution principles, architectures, or finalised structures.



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The Evaluation phase reviews the design following Generation. The input to this phase could therefore be a solution principle, architecture, or finalised structure. The design could be scrutinised with physics-based methods such as Finite Element Analysis (FEA) to assess its feasibility. A tool that provides Evaluation should output a measure of the viability of the chosen solution.

To support Implementation a tool needs to progress the finalised design to a prototype or product. To do this fully in an engineering machine system context would require the integration of a process such as AM into the toolchain. Partial exhibition of Implementation could be achieved with integration of a method of Computer Aided Manufacture (CAM) such as slicing for AM.

## 4. Tool mapping

The rows of the flowchart in Figure 3 show the mapping of the 15 tools against the position they hold within the design process. The GD tools can be split into two categories, the early-stage general purpose tools and the late-stage specialist tools. The placement of the four traditional and non-generative tools provides context to the framing of the generative Concept and Embodiment stage tools.

The columns of the flowchart in Figure 3 demonstrate the phases of Howard's creativity process that each of the design tools cover. In this figure the generative capability of the tools is represented by the boxes containing the tool's name in bold, the normal font names represent capability that is feasible within the wider software package if augmented by a human designer, and the non-generative tools are distinguished with italicised names.

ChatGPT and DALL-E are considered to perform some of the steps of Task Clarification as part of their generative capability. Both are capable of Generation of a problem definition however require a prompt including an obstacle and an objective. For example, ChatGPT presents solutions that necessitate it having generated problem definitions. When prompted ‘There is a closed door in front of me. I need something the other side of the door.’, it answers with a list of potential solutions including ‘Use a key’ and ‘Check if it's unlocked’. This shows the tool is capable of Generation in the Task Clarification stage. Meanwhile, the requirement for a clearly stated obstacle demonstrates that ChatGPT is incapable of Analysis in the Task Clarification stage. Similarly, neither tool performs any form of Evaluation upon the derived problem definitions before they are Implemented.

The Embodiment capability of Amesim and Simulink is entirely human designer driven. It requires a human designer to select, organise and connect the components to create a system. These tools' GD capability sits within the Detail design stage as explained in Section 3.2. Amesim and Simulink are primarily multi-physics simulation tools. As such, they have capacity for Evaluation of the designs they produce in multiple contexts given the input of a human designer. Ansys, Inspire, Abaqus and Sulis are all capable of Evaluation for the same reason.

CATIA, Fusion 360 and Siemens NX are all CAD/ CAM tools. This extended capability, along with their simulation packages, enables these tools to demonstrate aspects of Implementation and Evaluation when operated by a human designer. The CAM capability does not provide full Implementation but is the first step toward a physical product as discussed in Section 3.3.

## 5. Discussion

The Analysis phase of the Task Clarification stage of Pahl and Beitz (2007) engineering design process model stands notably empty in Figure 3. In this stage designers consider that there is an obstacle to an objective. Howard et al. (2007) that the creative process is present within each stage of the design process, acting as the mechanism by which the input of the stage becomes the output: The Analysis phase of Task Clarification encompasses the identification of the obstacle. The Generation phase synthesises problem definitions. In Evaluation the definitions are assessed for appropriateness. Finally, in the Implementation stage the problem is defined in a way that allows a Concept design stage tool to interpret it. These phases of Task Clarification stand separately from the Analysis phase of the later design stages where defined problems are interpreted. This study argues that no design tools exist for performing Analysis or Evaluation at the Task Clarification stage. This is discussed further below.



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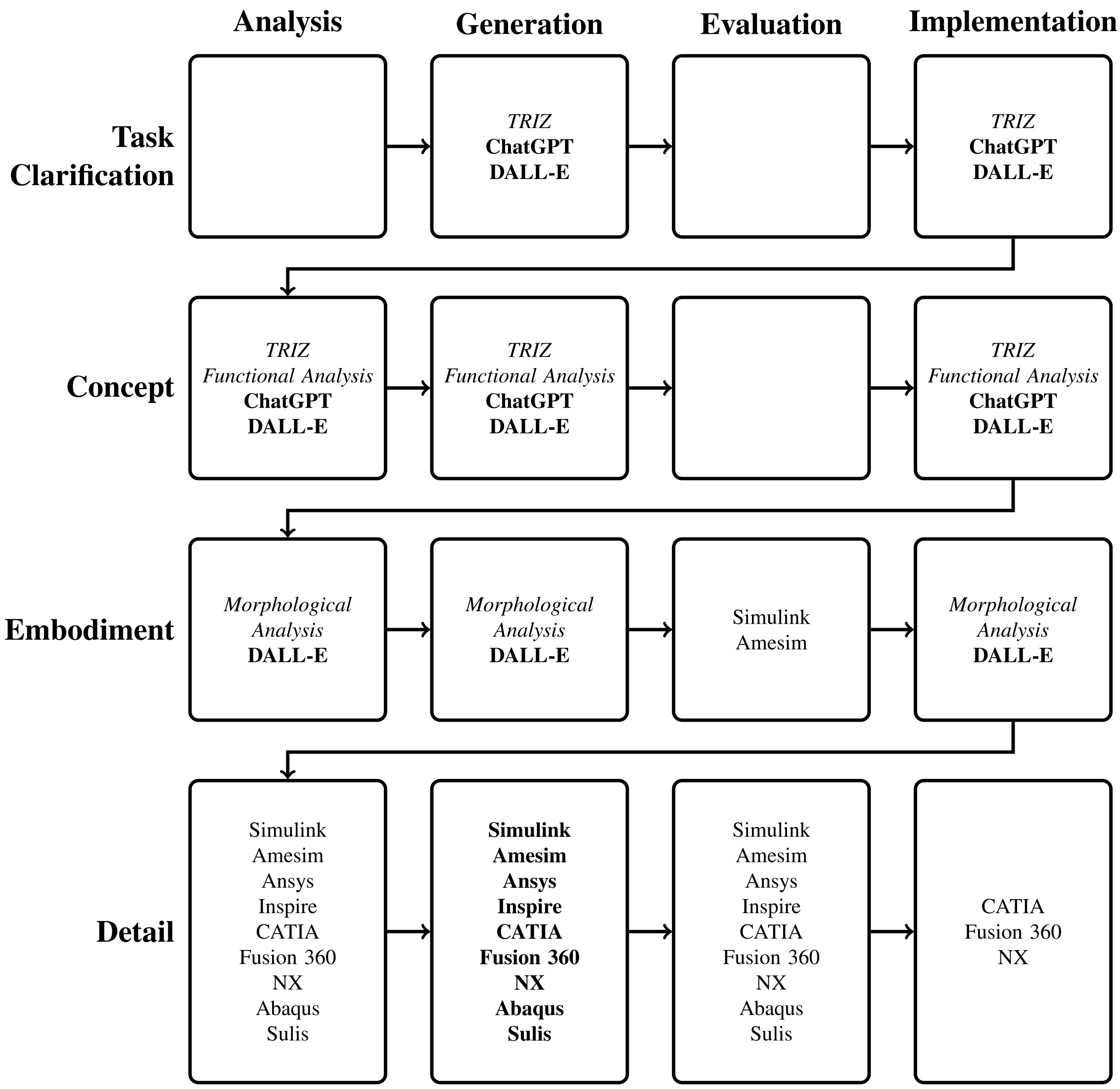


**Figure 3. Illustration of the phases of Howard's creative process that the tools exhibit within each stage of the design process. Location of bold tool names indicate position of the tools core generative capability, normal names show tool functionality that is feasible in conjunction with a human designer and italicised names represent the non-generative tools**

The generative AI design tools capable of operating in the early Concept and Embodiment design stages are general purpose tools built upon natural language processing. The flexibility afforded by the text representation of designs allows the tools to operate across broad design principles with high abstraction and ambiguity (Filippi, 2023). This generality and therefore lack of specialised physics models prevents these tools from operating in the Detail design stage, however.

The Detail design stage contains specialist engineering tools that cannot support earlier stages of the design process. The specificity at this late stage requires the accuracy of high-fidelity physics models. Like general purpose tools, the specialised nature of engineering tools prevents them from providing the flexibility required by earlier design stages due to their application of an existing rigid knowledge base. These extremes of general and specialised tools highlight a gap unfilled by GD tools and represents a trade-off between the depth of insights a tool can provide and the breadth of its applications.

Ordinarily industry focuses upon development of high readiness level tools whilst academia works upon more novel approaches to problems. Over the past couple of years, however, the development of generative tools has been driven principally by large technology companies, with OpenAI a standout example. In contrast, academic progress has been focused particularly upon specialist engineering problems (Mountstephens and Teo, 2020; Acosta-Zazueta, Alcaide-Marzal and Diego-Más, 2021). This



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approach has meant that methods developed by academia contribute mainly to development of Detail stage generation but leaves the earlier design stages untouched.
Given the current capability of design tools, the human designer remains with two important roles to play in creative engineering design. First, none of the tools can operate within the Analysis or Evaluation phases of the Task Clarification design stage. Pfeifer and Bongard (2006) suggest that the abilities needed to exhibit Analysis in Task Clarification requires immersion within an unconstrained environment such as the physical world and a pressure to mature. Current GD tools are heavily reliant upon constraints to guide their synthesis. The specialist engineering tools are unable to exhibit Task Clarification because of their inability to generalise and approach the problem from multiple directions. The Evaluation phase of the Task Clarification and Concept stages are similarly unpopulated because such tools would require a limitless yet precise knowledge base to give accurate predictions of feasibility given only an abstract input. These weaknesses demonstrate the need for a human designer to identify a problem, research it, then define its scope, constraining the problem for the tool.
Figure 3 demonstrates that engineering tool software packages are capable of more aspects of the creative process than Generation. These capabilities are currently disparate, however. This opens the second avenue of contribution from the human designer. The wider Fusion 360 software package is capable of GD, FEA and CAM but needs a designer to link the three appropriately. Increased integration of tool capabilities through linked cloud-based software packages facilitates rapid and easy use of the various functionalities, enabling increased design creativity. Model Based Systems Engineering is an example of linking these capabilities but is mainly human actuated (Madni and Sievers, 2018).
The emergence of generative AI tools and their use for engineering design suggests future development opportunities for systems less reliant on human guidance. Specifically, the ability to train generative AI on large knowledge bases could in future allow gaps to be bridged from early to late-stage design.
Using the phases of the creative process that the tools' exhibit allows a gauge to be taken of tool creativity. Importantly, none of the tools are capable of functioning generatively in all the four phases of the creative process and each rely on human designers in some areas. This need for human designer guidance implies that it is more appropriate to think of GD tools as aiding the creative process and enhancing the designer's creativity, rather than as creative themselves. For a tool to demonstrate creativity it would need to be capable of autonomously progressing through each of the phases of the creative process within one or more design stages.

## 6. Conclusion

This study aimed to establish the scope current generative design tools across the design process and how creative the design tools are. A desktop review was performed of 15 design tools, including 4 non-generative tools for comparison. The review considered the tools' inputs, the nature of their algorithm, and their output. Using these characteristics, the capability of each tool was mapped to the Pahl and Beitz (2007) engineering design process. It was found that the generative capability of all the engineering specific tools sat within the Detail design stage and only generative AI tools could operate in the earlier concept and embodiment design stages in a generative capacity. This highlights the gap between the use of flexible general-purpose tools which can define problems and specialist engineering tools better suited to the rigid application of knowledge bases for late in the design process.
To explore the creativity of the tools they were mapped also against the four phases of Howard et al. (2007)'s creativity process. Here it was found that the specialist engineering tools exhibited just the Generation phase autonomously with only the natural language based generative AI tools supporting other phases of the creative process. The implication is that generative design tools are only capable of assisting the creativity of the designer as they do not exhibit all phases of the creative process. The emergence of generative AI tools suggests that the aspects of creativity the tools display will likely grow however the intervention and guidance of humans with remain necessary for creative design for the foreseeable future.

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## References


Abdelmohsen, S.M. (2013) ‘Reconfiguring Architectural Space Using Generative Design and Digital Fabrication: A Project Based Course’, in Proceedings of the XVII Conference of the Iberoamerican Society of Digital Graphics - SIGraDi: Knowledge-based Design. Valparaiso, Chile: Editora Edgard Blücher, pp. 391–395. Available at: https://doi.org/10.5151/despro-sigradi2013-0074.

Acosta-Zazueta, G., Alcaide-Marzal, J. and Diego-Más, J.A. (2021) ‘GENERATIVE DESIGN SOFTWARE AND DIFFERENT APPROACHES’.

Altair (2023) 3D Printing Generative Design Software | Altair Sulis, Default. Available at: https://altair.com/sulis (Accessed: 13 October 2023).

Amabile, T.M. (1996) Creativity in context: Update to ‘The Social Psychology of Creativity.’ Boulder, CO, US: Westview Press (Creativity in context: Update to ‘The Social Psychology of Creativity.’), pp. xviii, 317.

Ansys (2021) Ansys Topology Optimization | Lightweighting & Shape Optimization. Available at: https://www.ansys.com/applications/topology-optimization (Accessed: 1 November 2023).

Arciszewski, T. (2018) ‘Morphological Analysis in Inventive Engineering’, Technological Forecasting and Social Change, 126, pp. 92–101. Available at: https://doi.org/10.1016/j.techfore.2017.10.013.

Askland, H.H., Ostwald, M. and Williams, A. (2010) ‘Changing Conceptualisations of Creativity in Design’.

AutoDesk (2023) Fusion 360 Generative Design Extension. Available at: https://www.autodesk.co.uk/products/fusion-360/generative-design-extension (Accessed: 2 November 2023).

Barda, A. et al. (2023) ‘Generative Design of Sheet Metal Structures’, ACM Transactions on Graphics, 42(4), p. 116:1-116:13. Available at: https://doi.org/10.1145/3592444.

Bernal, M., Haymaker, J.R. and Eastman, C. (2015) ‘On the role of computational support for designers in action’, Design Studies, 41, pp. 163–182. Available at: https://doi.org/10.1016/j.destud.2015.08.001.

Bing (2023) Bing Image Creater - powered by Dall-E3, Bing. Available at: https://www.bing.com/images/create/image-creater/646a1181ae664496a8f83e5bb8607d35 (Accessed: 6 November 2023).

Brisco, R., Hay, L. and Dhami, S. (2023) ‘EXPLORING THE ROLE OF TEXT-TO-IMAGE AI IN CONCEPT GENERATION’, Proceedings of the Design Society, 3, pp. 1835–1844. Available at: https://doi.org/10.1017/pds.2023.184.

Caetano, I., Santos, L. and Leitão, A. (2020) ‘Computational design in architecture: Defining parametric, generative, and algorithmic design’, Frontiers of Architectural Research, 9(2), pp. 287–300. Available at: https://doi.org/10.1016/j.foar.2019.12.008.

Caldas, L. (2008) ‘Generation of energy-efficient architecture solutions applying GENE_ARCH: An evolution-based generative design system’, Advanced Engineering Informatics, 22(1), pp. 59–70. Available at: https://doi.org/10.1016/j.aei.2007.08.012.

Cross, N. (1982) ‘Designerly ways of knowing’, DESIGN STUDIES, 3(4).

Das, S. et al. (2023) ‘A case study: Analyzing the structure and optimizing the design of the aero handlebar assembly for the bicycle used in Japan’s Olympic games’, Engineering Reports, p. e12783. Available at: https://doi.org/10.1002/eng2.12783.

Dassault Systemes (2020) Generative Design Engineering. Available at: https://events.3ds.com/generative-design-engineering (Accessed: 1 November 2023).

Design Council (2006) Framework for Innovation - Design Council. Available at: https://www.designcouncil.org.uk/our-resources/framework-for-innovation/ (Accessed: 7 November 2023).

Díaz, G. et al. (2021) ‘Applications of generative design in structural engineering Aplicaciones del diseño generativo en la ingeniería estructural’, 36.

Filippi, S. (2023) ‘Measuring the Impact of ChatGPT on Fostering Concept Generation in Innovative Product Design’, Electronics, 12(16), p. 3535. Available at: https://doi.org/10.3390/electronics12163535.

Gadd, K. (2011) TRIZ for engineers: enabling inventive problem solving. Chichester: Wiley.

Gero, J.S. and Kannengiesser, U. (2004) ‘The situated function–behaviour–structure framework’, Design Studies, 25(4), pp. 373–391. Available at: https://doi.org/10.1016/j.destud.2003.10.010.

Howard, T., Culley, S. and Dekoninck, E. (2007) ‘CREATIVITY IN THE ENGINEERING DESIGN PROCESS’, in. ICED07.

Johnsen, S. (2013) Structural Topology Optimization. NTNU Norway. Available at: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/241794.

Lim, S.T. and Wong, T.T. (2018) ‘Unleash the potential of additive manufacturing with topology optimization’, in. 6TH INTERNATIONAL CONFERENCE ON PRODUCTION, ENERGY AND RELIABILITY 2018: World Engineering Science & Technology Congress (ESTCON), Kuala Lumpur, Malaysia, p. 040007. Available at: https://doi.org/10.1063/1.5075571.





https://doi.org/10.1017/pds.2024.71 Published online by Cambridge University Press

Little, A.D., Wood, K.L. and McAdams, D.A. (1997) 'Functional Analysis: A Fundamental Empirical Study for Reverse Engineering, Benchmarking and Redesign', in Volume 3: 9th International Design Theory and Methodology Conference. ASME 1997 Design Engineering Technical Conferences, Sacramento, California, USA: American Society of Mechanical Engineers, p. V003T30A015. Available at: https://doi.org/10.1115/DETC97/DTM-3879.
Madni, A.M. and Sievers, M. (2018) 'Model-based systems engineering: Motivation, current status, and research opportunities'. Available at: https://doi.org/10.1002/sys.21438.
MathWorks (2023) Simulink - Simulation and Model-Based Design. Available at: https://uk.mathworks.com/products/simulink.html (Accessed: 10 November 2023).
Menninger, B., Berroth, J. and Jacobs, G. (2022) 'Development of System Alternatives using Generative Engineering', in 2022 IEEE International Symposium on Systems Engineering (ISSE), Vienna, Austria: IEEE, pp. 1–6. Available at: https://doi.org/10.1109/ISSE54508.2022.10005535.
Mitchell, W.J. (1975) 'The Theoretical Foundation of Computer-Aided Architectural Design'.
Mountstephens, J. and Teo, J. (2020) 'Progress and Challenges in Generative Product Design: A Review of Systems', Computers, 9(4), p. 80. Available at: https://doi.org/10.3390/computers9040080.
Oxman, R. (2008) 'Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium', Design Studies, 29(2), pp. 99–120. Available at: https://doi.org/10.1016/j.destud.2007.12.003.
Pahl, G. and Beitz, W. (2007) Engineering design: a systematic approach. 3rd ed. Edited by J. Feldhusen and K.H. Grote. London: Springer.
Petrov, V. (2023) Talented Thinking: TRIZ. Cham: Springer International Publishing. Available at: https://doi.org/10.1007/978-3-031-15505-5.
Pfeifer, R. and Bongard, J. (2006) How the body shapes the way we think. The MIT Press.
Putman, V.L. and Paulus, P.B. (2009) 'Brainstorming, Brainstorming Rules and Decision Making', The Journal of Creative Behavior, 43(1), pp. 29–40. Available at: https://doi.org/10.1002/j.2162-6057.2009.tb01304.x.
Ramesh, A. et al. (2022) 'Hierarchical Text-Conditional Image Generation with CLIP Latents'. arXiv. Available at: http://arxiv.org/abs/2204.06125 (Accessed: 7 November 2023).
Sarkar, P. and Chakrabarti, A. (2007) 'DEVELOPMENT OF A METHOD FOR ASSESSING DESIGN CREATIVITY'.
Sawyer, R.K. (2006) Explaining creativity: the science of human innovation. Oxford ; New York: Oxford University Press.
Scopus (2023) Scopus - Document search. Available at: https://www.scopus.com/search/form.uri?display=basic#basic (Accessed: 24 November 2023).
Siemens (2023a) Siemens NX Generative Design Software, Siemens Expert Partner. Available at: https://www.ddsplm.com/products/nx-cad-generative-design/ (Accessed: 1 November 2023).
Siemens (2023b) Simcenter Amesim, Siemens Digital Industries Software. Available at: https://plm.sw.siemens.com/en-US/simcenter/systems-simulation/amesim/ (Accessed: 30 October 2023).
Singh, V. and Gu, N. (2012) 'Towards an integrated generative design framework', Design Studies, 33(2), pp. 185–207. Available at: https://doi.org/10.1016/j.destud.2011.06.001.
Snider, C.M. (2014) Characterising the Creative Behaviour of Designers within the Late-Stage Engineering Design Process.
Starodubcev, N.O. et al. (2023) 'Generative Design of Physical Objects using Modular Framework', Engineering Applications of Artificial Intelligence, 119, p. 105715. Available at: https://doi.org/10.1016/j.engappai.2022.105715.
Wang, Z., Zhang, Y. and Bernard, A. (2021) 'A constructive solid geometry-based generative design method for additive manufacturing', Additive Manufacturing, 41, p. 101952. Available at: https://doi.org/10.1016/j.addma.2021.101952.
Wodehouse, A. and Casakin, H. (2022) 'Design Creativity in Architecture and Engineering', Buildings, 12(10), p. 1552. Available at: https://doi.org/10.3390/buildings12101552.