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ENGINEERING DESIGN – DOES AI CHANGE THE PATH OF EVOLUTION IN METHODS & TEACHING?

Tim WOOLMAN
University of Southampton, United Kingdom

ABSTRACT

Engineering design tools are evolving, where AI can enhance speed and quality. Which of the current and future developments will change the teaching of engineering design? Text-to-image tools appear to be a precursor to text-to-design tools which will offer sensible-looking outputs in areas where many design precedents enable interpolation. However, where novelty is the goal, especially in new design spaces, human understanding of multivariate decisions, including where empathy for welfare and delight are considerations, is hard to express as merit functions for machines to learn. AI is already improving productivity in collating information relevant to discovering and defining performance requirements, and information on design precedents and available supplies. It can also improve the validity of simulation during the creation and refinement of design solutions and automate the application of engineering drawing language to a final design specification. We suggest engineering students' future selves will value their, i) learning to use human interaction to characterise performance requirements, ii) gaining knowledge as to how (well) and why existing engineering designs work, iii) practicing sketching as a means to visually communicate design ideas, iv) using CAD to experiment with state of the art modelling and simulation functionality while creating their own system designs, v) developing proficiency in engineering drawing language, and, vi) learning to make, break and tinker in workshops and to explore the potential & limitations of production. A familiar path, in which to add AI experiments.

Keywords: Engineering design, design methods, AI

1 INTRODUCTION

The interface to engineering design methods has evolved from drawing boards and blueprints to use of CAD software on screen and in some cases the 3D manipulation of models viewed in augmented reality. Is engineering design decision making also due to evolve, or is artificial intelligence (AI) unlikely to supplant the disciplines and practices introduced and developed in engineering design teaching?

There is certainly ambition for AI to synthesise decision making when manipulating form and material. Generative design already distributes material according to rules for both structural performance and manufacturability. Can distributed computing emulate expertise applied to optimise utility, aesthetic and tactile appeal? If so, what will engineers no longer do while designing; what might not need to be taught?

2 WHAT CAN AI DO WHICH CAN BE APPLIED TO ENGINEERING DESIGN

We know AI chatbots, based on large language models, can process languages, applying rules to search, summarise and generate text or computer code, in response to prompts we enter. When trained to relate images to their meaning, AI tools can generate new images and hence video. This appears to imply an understanding of 2D and 3D form. However, there are many design rules and parameters to account for in stepping from a synthesis of elements of a 3D image to an allocation of materials and forms in a 3D design space to meet a combination of requirements.

The probabilistic nature of AI selecting beneficial changes from wherever it starts, introduces uncertainty about its suitability to apply to a creative design process. ChatGPT creators Open AI suggest users should be aware of the tool offering "plausible sounding but incorrect or nonsensical answers" [1], as reinforcement learning must iterate from model proposals - it cannot jump to a trainer's truth.

Improving outputs from chatbots led to 'prompt engineering', helping users structure inputs. The move from using text-to-image tools towards exploring text-to-design, may start offering some sensible-looking outputs. However, as Joseph Flaig asks, "Can a programme that does not understand why a design might work or not work be trusted to consider the potential harm of an issue down the line?" [2].

To limit poor results, AI models can be trained on data which engineers trust to be valid, for example data generated and stored internal to an organisation. Risky extrapolation can be limited by using rules. Engineers may favour deterministic tools, where AI extends optimisation calculations to search for unique solutions to a defined and prioritised combination of parameters in a validated simulation space. Can AI go further to emulate human decision-making during design to prescribe form and material in response to chosen scenarios? Generative design in the sense implemented in current CAD software such as Fusion 360® appears to offer creative assistance though still providing a choice of different solutions with different balances of strength, stiffness, weight and machinability for single components in a defined space between interfaces. The topology optimisation – removal of material until the most efficient part geometry meets intent – may be used to create variants of each design; variants prioritising different optimisation targets. The lightest design would have a different form than that seeking the lowest cost, or with Multiphysics tools engaged, the lowest drag or the most thermally efficient.

BlankAI [3] starts earlier in the concept design space. Having been trained on existing 3D designs and their associated meta-data, the algorithm learns from associating design features to specific prompts. BlankAI can generate and edit forms for different types of vehicles and enhance or diminish attributes such as 'modern,' 'sporty' and 'rugged' (Figure 1). Coupled with rendering, preparing concept designs, traditionally the preserve of a skilled sketching process, appears enhanced, or is it just derivation?

Figure 1. Example BlankAI tool offering control of form using semantic inputs for the attributes of AI-derived vehicle concept designs [3]

Figure 2. Example Leo™ text-to-CAD response to the input "tricycle" [4]

Automated morphing between likely vehicle shapes is based on synthesising the shapes and attributes of existing vehicles. No inputs are sought for other functional performance requirements such as carrying capacity, energy efficiency, durability, safety or environmental impact. Nevertheless, where design precedents can be selected and their form and features coded to some degree in relation to desirable attributes, a number of concept bodies can be created quickly from semantic prompts.

From a starting concept, basic shapes of products in CAD software can be analysed and optimised more conventionally, provided performance parameters can be entered and simulated. The next step is to split a body into a structural assembly of production-friendly parts. Leo™, "the world's first engineering design copilot" [4], is an alpha version tool, offering a text-to-CAD ability to generate an assembly of 3D parts for CAD export. While the ambition is impressive, there is much tricky work to do (Figure 2).

Mechanisms comprising several elements are a further interesting case. Permutations in geometry, strength and efficiency for example, all interact also through interfaces between elements which are harder to simulate, such that the number of combinations to explore is much larger. Also, the data needed for AI to interpolate between existing simulations of variants is much less available than say, vehicle body shapes. From a starting mechanism design, depending on the type and complexity, a process of experimentation could begin to both test the suitability of incremental changes in each geometric and material parameter, and confirm dynamic responses to the intended mechanism outputs remain suitable. As with optimisation, local maxima may restrain an algorithm from finding a greater maximum elsewhere. Mapping the whole design space for structures + mechanisms is a computational challenge.

Can more powerful computing algorithms further emulate the expertise applied in the engineering design process to 'understand' and simultaneously maximise utility, aesthetic and tactile appeal?

Achieving novel engineering solutions remains difficult. As we try to distinguish speculation from predictions as to how AI tools will evolve, and which areas of the engineering design process are likely to change, we should consider the different disciplines and activities in the engineering design process.

3 ENGINEERING DESIGN PROCESS – AS TAUGHT TO UG STUDENTS

The engineering design process we currently teach has been chosen to follow a double diamond. The first stage is discovering and defining requirements to establish a solution-neutral Performance Specification addressing all necessary and desirable requirements, validated from stakeholders' input.
The second stage is to create and refine a Specification of the Design solution to meet the Performance Specification. These design stages are illustrated in the example engineering process flow in Figure 3.

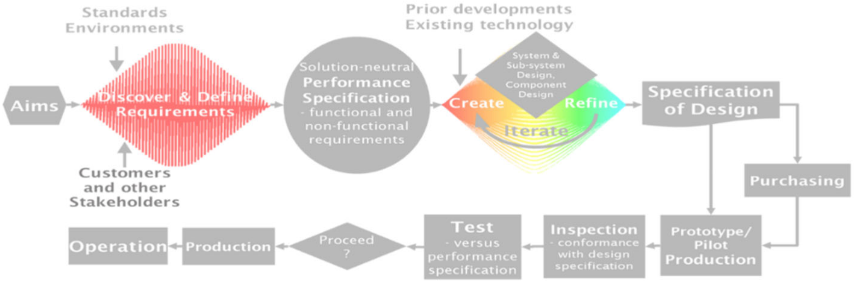

Figure 3. Example engineering process flow, featuring the double diamond design process

Considering these two stages we can look at the methods used by engineering designers and how AI tools can now, and may in future, enhance those methods such that our teaching would need to evolve.

3.1 Can AI enhance decision making to discover and define requirements?

Discovering and defining requirements, incorporates two types of knowledge compilation,

a) information sourcing and filtering for conditions and behaviours in a predictable scenario, and,
b) capturing information relevant for a new combination of conditions and stakeholder behaviours.

In predictable scenarios information sourcing and filtering is highly suited to enhancement using AI.
AI is less suited to exploring conditions and behaviours without direct precedent. Speculating on what is relevant to new environments requires human judgement to distinguish the plausible from the realistic.

3.2 What do we need to teach so students can discover and define requirements?

With or without using AI for enhancing decision making to discover and define requirements, we need to teach students to characterise needs and desires by pursuing a range of human interactions to explore environments and conditions. They may revisit performance scenarios where the set of requirements has seemingly converged to a common understanding, as the data on which an AI model relies may lag real trends. The thresholds for what is necessary and the emphasis between competing priorities may change. Hence students should always be prepared to justify selecting requirements by grounding them in what stakeholders currently believe to be valid. They may pursue unrealised needs with innovation potential. Students who learn to fully explore a performance scenario and its requirements are more likely to question assumptions and jump towards new possibilities, promoting novelty and disruptive potential.
In any case, deeper understanding of design requirements is highly likely to ease their role in the process of generating, selecting and refining solutions. The challenge, as always, is to make a performance specification solution neutral. Perhaps AI can be trained to identify solution-partiality as a useful check.

3.3 Can AI enhance decision making to create and refine solutions?

The second design stage, to create and refine solutions, can be broken down into various types of decision making, in order to consider what AI can offer to enhance design methods.

3.3.1 Solution finding

Solution finding to prepare concepts for evaluation, includes seeking a combination of

1) **extrapolations from relevant design precedents**, to reduce inefficient re-invention.
   AI tools are adept at searching for design precedents once they recognise and are trained to attribute performance to designs and match the performance with the performance requirements in a scenario.
2) **more fundamentally derived solutions** generated from finding matching examples of the generic means of solving a similar type of problem. The ability to derive solutions grows from examining the principles underpinning designs, learned by applying curiosity and training in how they work.

Methods to expand the range of different concepts typically rely on intuitively assembling ideas. We might ask: How does nature solve any similar problems? How would a cartoon character try to achieve the intended performance? Adding AI's 'nonsensical answers,' may complement our brainstorming.

Engineers faced with contradicting performance objectives, can find value using TRIZ[1] processes which are more systematic. Enhancing TRIZ with AI is underway. However, a review by Ghane et al. [5] suggests, "most research conducted so far strongly relies on manual intervention by experts… TRIZ fundamentally relies on human cognitive mechanisms…" If AI tools were, in due course, to automate TRIZ processes, its currently limited adoption in engineering industry might spread.

3.3.2 Sourcing information relevant to a Performance Specification such as external supplies

If design engineers spend a third of their time looking for information, including for example external supplies of material and components, then use of AI tools enhancing the finding of such information and judging its suitability, will evolve. Some supplies are not currently described in ways which can be attributed meaning electronically, so publishing will evolve to support supply chain development. No new skills in engineering design appear to be needed, and a normal make or buy analysis should follow.

3.3.3 Solution embodiment

Solution concepts need to be embodied with sufficient detail to evaluate their performance. A design structure, a combination of production-friendly parts, needs to be determined. Given many permutations to explore, the choices are difficult to navigate. AI tools are therefore difficult to train, and they can hardly gain a feel for materials and their manipulation. How easy is the tricycle in Figure 2 to make?

Engineering designers who are trained in workshop processes to understand material characteristics as well as how to create manufacturable forms and features have an advantage. Apple's head designer, Jonathan Ive, in 2014 suggested student designers who do not learn how to make things in workshops and rely too much on computers, can create dreadful designs which "look really palatable" [6].

Traditionally the process of embodiment would start with sketching, allocating material to a form to enable visual evaluation. Leonardo Da Vinci would recognise the value of sketching also through computer aided sketch tools to aid manipulation. The Leo™ tool accepts a sketch input to help guide it.

3.3.4 Solution evaluation - analysis and choice

Once modelled in CAD with material choices applied, simulation of functional performance and manufacturability, as well as costing and initial environmental impact assessment become possible, to inform changes needed, both within options and choosing between options. Simulated results are not perfect, but sufficient to compare design options.

AI is enhancing the selection of suitable sources of data for software and improving the emulation of performance conditions, the attribution of costs and the veracity of environmental impacts calculated.

Provided there is further feedback into simulation software through data derived from physical testing, real world costing and production processes, simulation will further improve in terms of trustworthiness.

Bringing CAD modelling and simulation together (ModSim) enables design changes to be simulated very quickly. A logical progression is for CAD software to pre-emptively anticipate the kind of changes a designer might make and to have simulated the consequences sufficiently to suggest those changes.

Beyond that, an engineering designer might accept a simulation tool trying to iterate towards improvements to match a profile of performance parameters, seeking to maximise overall merit. For this, merit functions would need to be established for each performance parameter. As this is not common, AI might be used to devise tests to elicit from stakeholders the relative importance of utility, cost, aesthetic and tactile appeal for example. However, testing human responses for a novel or unfamiliar designs is difficult until they are embodied. So, test results are likely to be imprecise until a physical embodiment can be experienced. Even then test conditions are unlikely to be fully valid – what measurements represent the welfare of users of a design and how many test cases are needed to explore and quantify or 'understand' what makes users productive, healthy, happy and occasionally delighted? More importantly should a designer trust a tool to predict the harm of an issue arising down the line?

For engineers to take responsibility for their designs they need to continue to understand sufficiently the validity and limitations of decision-making to evaluate designs and present favourable choices.

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[1] TRIZ, 'the theory of inventive problem solving', is a systematic method for problem solving using analysis and forecasting, created by Genrich Altshuller observing patterns of invention in patents.

3.3.5 Solution specification for communication

Specification of an engineering design will either use an engineering drawing to control variation of material properties and geometry, or Model Based Definition where tolerances are defined directly alongside geometric parameters. MBD aids tolerance modelling and verification by 3D measurement.

Through learning what is understood from examples of applying engineering drawing language, AI can assist in creating engineering drawings. Autodesk® Automated Drawings in Fusion 360®, "will provide the ability to create fully dimensioned 2D drawings from 3D models with the click of a button." [7]

As with any language, though the conventions of engineering drawing appear highly standardised, if we are to minimise costly misunderstanding, it is as well to remain proficient by being involved in a process of checking drawings, and to be ready to adapt them to suit those receiving the communication.

3.4 What do we need to teach so students can create and refine solutions?

3.4.1 Solution finding

To prime solution generation, we generally expose students to a limited set of examples of what should work as an engineering design solution and offer a limited range of experience in testing their usefulness. Students therefore adopt and adapt limited solutions. They need to constantly examine how (well) the engineering designs they see work. Through such evaluation, they can develop their judgement and apply it early in the design process, to decide what design precedents are relevant and which principles can best generate alternative solutions.

Teaching what a TRIZ tool is doing may still be interesting to students, so using TRIZ manually with AI-enhancements in due course, is an option. Acquiring knowledge to use it well can follow as needed.

With the performance specification and any design precedents and solving principles in mind, some concept ideas can be generated. Experimenting with text-to-design tools will be interesting, as well as interpolating from design precedents and initial concepts. However, we intend students to develop engineering judgement also in relation to parameters in a new performance scenario and to introduce novelty in all cases. Teaching techniques to broaden their choice of creative concepts remains valuable.

3.4.2 Sourcing information relevant to a Performance Specification such as external supplies

As AI tools evolve to enhance searching for information and supplies, and suppliers further improve their content to be found more easily, no new skills in sourcing engineering supplies appear to be needed.

3.4.3 Solution embodiment, evaluation - analysis and choice

To embody design concepts, engineering students need to practice sketching as a means to visually communicate design ideas, both to themselves and to others. Given the number of permutations to explore can be large, even anticipating AI-enhanced navigation of some of the options cf. BlankAI offering semantic prompts, simulation can best assist decision making once the figurative blank sheet of paper contains a sketch, effectively annotated to attribute meaning as far as possible.

Then, to refine the concept as bodies are split into parts and mechanisms applied, students need to start to use CAD to experiment with state-of-the-art modelling and simulation functionality initially through exercises and then while creating their own system designs at a manageable scale. With material choices applied in CAD, simulation of functional performance and manufacturability as well as cost estimating, and the first phases of a life cycle environmental impact assessment become reasonable for students to practice. AI will assist with processing and presenting data for evaluation against the performance specification, sufficient to inform both changes to develop each option and choices between options.

Seeking to finally validate designs by seeking stakeholders' responses to the predicted and tested performance of novel designs, can contribute to extending the training of AI for wiser decision-making. Students practicing design development should learn their craft sufficient to train and recognise where they can learn from virtual assistants, as they would in their interactions as a team comprising members with complementary capabilities. Students who learn to make, break and tinker in workshops, extend their understanding of the potential and limitations of production, even if AI tools can feed back CAM and suppliers' responses into CAD. Students learn that a final design specification comes with uncertainties and risks. To address this testing is needed ahead of final specification for manufacture.

3.4.4 Solution specification for communication

Unless Model Based Definition becomes pervasive and legacy drawings are converted, students need to develop proficiency in using engineering drawing language, suited to different industry preferences.

4 CONCLUSIONS

As engineering design methods evolve, partly with AI tools applied where they can achieve faster and better quality, we see and anticipate changes in some methods applied during the double diamond process stages of discovering and defining requirements and creating and refining solutions. These changes can inform developments in the teaching of engineering design, though the intent and steps in the process, as well as many of the capabilities engineering designers value, remain the same.

AI tools are suited to probabilistically associating language, image, or other data such as material geometries with meaning, enabling semantic inputs to generate text, images or 3D models. There may be assistance in capturing the relevant aspects of a new scenario (with an unexplored combination of environments, conditions and behaviours), but human interactions are needed to characterise many typical performance requirements and to speculate sympathetically with a wide range of stakeholders.

Like engineering students, AI needs to learn with access to data valid for a performance scenario and feedback on merit during decision-making, to learn from design precedents and from design principles akin to those applied during invention. Anticipating text-to-design tools which will offer sensible-looking outputs, in new design spaces human understanding of multivariate decision making is hard for machines to learn, especially when empathy for welfare and delight are difficult to generalise and codify in merit functions to evaluate performance. Hence students need to continue to learn to characterise performance requirements from a wide range of stakeholders through analysing results from the kind of human interaction which may not already be expressed in accessible sources.

AI is already improving productivity in collating information relevant to discovering and defining requirements for specifying performance and information on design precedents and available supplies. It can also improve the validity of simulation during the creation and refinement of design solutions and automate the application of engineering drawing language to a final design specification.

5 RECOMMENDATIONS

While seeking to ensure the validity of these approaches, we recommend that engineering design teaching offers students the chance to continue to,

1) learn to characterise performance requirements from a wide range of stakeholders through the kind of human interaction which may not already be expressed in accessible sources,
2) gain knowledge as to how (well) and why existing engineering designs work,
3) practice sketching as a means to visually communicate design ideas,
4) start to use CAD to experiment with state-of-the-art modelling and simulation functionality while creating their own system designs at a manageable scale,
5) develop proficiency in engineering drawing language, unless MBD becomes pervasive, and,
6) learn to make, break and tinker in workshops and explore the potential and limitations of production.

therefore, to continue on a similar path to evolve teaching while also sharing experiments with AI.

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