Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/GC03.20250023
Published: February 2, 2026

Concept Generation and Evaluation Techniques in Product Design

Sayyad Zahid Qamar, Tasneem Pervez, Nasra Al Maskari and Moosa Al Kharusi
Department of Mechanical and Industrial Engineering
Sultan Qaboos University, Muscat, Oman
sayyad@squ.edu.om

Abstract

The conceptual design phase is a critical driver of innovation and performance in engineering product development, where early decisions determine over 70% of lifecycle costs and feasibility outcomes. This paper presents a comprehensive overview of structured techniques for concept generation and evaluation, highlighting their importance in balancing creativity with engineering rigor. It examines both traditional ideation methods (such as brainstorming, morphological analysis, TRIZ, functional decomposition, analogical reasoning, and SCAMPER), and visual approaches like C-Sketch and the 6-3-5 method. Empirically derived design heuristics are also discussed as cognitive stimuli for ideation diversity and novelty. Moreovert, modern computer-aided tools are explored, including generative design platforms, CAD-based sketching, knowledge-based systems, and AI-driven ideation frameworks that extend solution space exploration. The section on concept evaluation includes multi-criteria decision-making methods such as AHP, TOPSIS, weighted scoring models, Pugh matrices, and risk-informed approaches. Best practices and integration strategies are addressed to overcome cognitive biases, complexity, and subjectivity in decision-making. This paper serves as a guide for engineering educators, designers, and researchers, offering actionable insights into leveraging systematic creativity and evaluation to enhance product design outcomes. It concludes with recommendations for integrating emerging AI tools and collaborative platforms to support innovation in complex engineering environments.

Keywords

Creative product design, Concept generation techniques, Concept evaluation methods, Design heuristics, Computational design tools

1. Introduction

The product design process (Figure1) is a structured, iterative workflow that guides the development of a product from initial idea to final production (Nebulem 2025). It begins with Understanding, involving client discussions and market research, followed by the *Definition* stage, where a clear project brief or set of specifications is created. The process then moves to *Conceptualization*, where ideas are created, sketched and visualized. In the *Development* phase, these concepts are refined into detailed designs, leading to the *Prototyping* stage using tools like 3D printing or CNC. The *Testing* phase assesses the fit and function of the prototype, and finally, the *Manufacture* stage involves producing the actual components. Each stage includes review points, allowing the process to return to any earlier phase as needed for refinement and improvement (Kroll et al 1994). In other words, engineering design is an iterative process, rather than being serial in nature. Some authors may have slightly different names of these stages (Al Jahwari et al 2022).

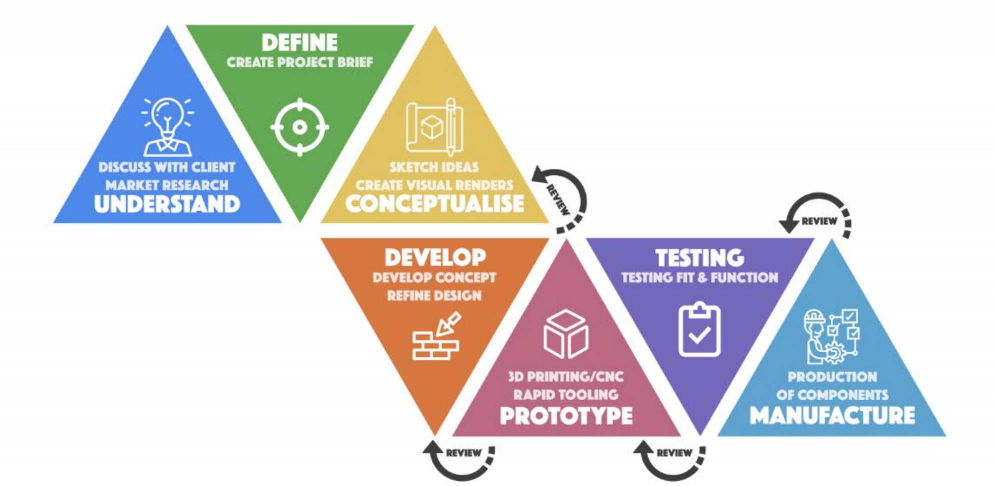

Figure 1. The engineering design process for product development

The ***conceptual design phase*** is foundational in this engineering product development process. Decisions made during this stage critically shape over 70% of a product's life cycle cost and profoundly influence its performance, manufacturability, and sustainability outcomes [Ullman 2020, Dieter and Schmidt 2013]. Despite (or because of) its early placement in the design process, the conceptual stage involves high levels of abstraction, incomplete information, and significant uncertainty, conditions under which structured ideation and rigorous evaluation techniques become indispensable (Qamar et al 2016).

Concept generation is the creative engine of engineering design, responsible for transforming clarified problem statements into a spectrum of feasible alternatives. Creativity and critical thinking are the principal drivers during this design phase (Qamar et al 2021; Qamar et al 2022; Qamar et al 2025). However, unguided ideation risks common pitfalls such as design fixation, limited solution diversity, and premature convergence (Chrysikou and Weisberg 2005). To mitigate these issues, researchers and practitioners have developed systematic techniques to encourage divergent thinking while maintaining technical feasibility. These range from traditional methods such as brainstorming and morphological analysis to modern tools such as TRIZ, SCAMPER, C-Sketching, and design heuristics (Osborn 1953; Altshuller 1999; Yilmaz et al 2016).

Advancements in computational design have further expanded the concept generation toolkit. Technologies like generative design platforms, AI-supported sketching, and knowledge-based systems now augment human creativity, enabling designers to explore larger and more complex solution spaces (Daly et al 2012). Yet, ideation alone does not guarantee successful design outcomes. The generated alternatives must be filtered, assessed, and selected based on well-defined performance, cost, risk, and usability criteria. To that end, concept evaluation techniques play a vital role in converging toward optimal solutions. Tools such as the Pugh matrix, weighted scoring methods, Analytic Hierarchy Process (AHP), and Go/No-Go screening allow for structured decision-making. Newer frameworks (like decision-based design and risk-informed analysis) incorporate uncertainty, lifecycle value, and stakeholder preferences into the evaluation process (Pugh 1991; Hazelrigg 1998).

This paper presents a detailed synthesis of concept generation and evaluation techniques, highlighting best practices, emerging tools, and integration strategies. The aim is to provide engineering educators, students, and practitioners with a comprehensive guide to systematic creativity and informed decision-making in design. A proper outcome-based pedagogical approach in engineering education can help foster creativity and out-of-the-box thinking needed for design of new products (Qamar et al 2016; Qamar 2018).

2. Role of Concept Generation in Engineering Design

Concept generation lies at the heart of the engineering design process. It serves as the pivotal link between problem definition and embodiment design, shaping the fundamental architecture, function, and feasibility of the final product.

While detailed design focuses on optimization and refinement, the conceptual phase is centered on exploration, generating a broad array of feasible alternatives before committing to a particular solution path; Figure 2.

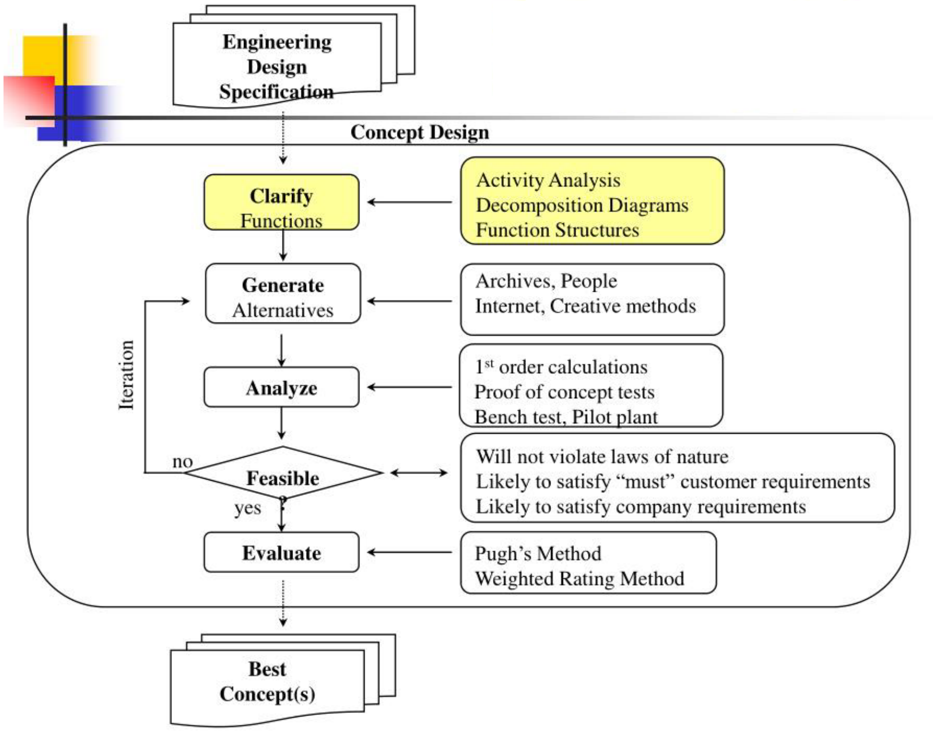

Figure 2. Steps in the concept generation process

According to Ullman (2020), concept generation is the second major stage in systematic design, following problem identification and specifications development. It is where divergent thinking is most critical, as premature convergence often leads to missed opportunities, limited creativity, and suboptimal performance. The quality of early design concepts strongly influences the downstream phases, affecting not only technical outcomes but also cost, risk exposure, and sustainability. Dieter and Schmidt (2013) argue that the greatest leverage for design innovation resides in this phase, and that teams must actively avoid fixation by applying structured ideation techniques and encouraging multidisciplinary collaboration. In this regard, teaching engineering students about sustainability practices in design and manufacturing becomes critical (Qamar et al 2024; Qamar et al 2023).

The goal of concept generation is not to arrive at a perfect solution, but to populate the design space with viable, diverse alternatives that can later be evaluated against engineering, economic, and stakeholder criteria. A well-executed concept generation process should yield ideas that vary across multiple dimensions (function, form, scale, and technology), enabling more robust trade-off analysis and increasing the likelihood of innovative outcomes (Yilmaz et al 2016). Furthermore, concept generation supports risk mitigation in high-stakes design environments by explicitly exploring fallback or alternative configurations. This is especially vital in sectors such as aerospace, automotive, bulk manufacturing (Arif et al 2001) and medical devices, where failure to evaluate sufficient alternatives early can lead to cost overruns or design failures with significant consequences (Cooper 2017).

In academic and industrial contexts, the role of concept generation has also expanded to include support for systems thinking, modularity, and platform design strategies. Effective ideation in this phase not only fosters creativity but also contributes to lifecycle efficiency by identifying reuse opportunities, simplifying manufacturing, and aligning with organizational design standards (Ulrich and Eppinger 2020). In summary, the conceptual design phase, driven by systematic concept generation, is where the foundation for design excellence is laid. Without broad exploration, even technically competent teams risk underperformance due to missed innovation or misaligned design assumptions.

3. Structured Techniques for Concept Generation

Concept generation can be greatly enhanced through the use of structured techniques that guide ideation while maintaining engineering rigor. These methods help teams overcome cognitive biases, expand the solution space, and ensure technical feasibility. This section reviews several widely adopted and well-documented techniques.

3.1 Brainstorming

Brainstorming remains one of the most widely used creativity techniques due to its simplicity and effectiveness in generating a large number of ideas rapidly. Originating from Osborn's foundational work (Osborn 1953), it emphasizes free-flowing idea generation without immediate judgment, encouraging even wild or unconventional concepts. To maximize effectiveness, structured brainstorming sessions use guidelines such as deferring criticism, encouraging quantity over quality, and building upon others' ideas (Pahl and Beitz 2007). Despite its informal nature, when combined with facilitators and targeted prompts, brainstorming can yield rich ideation outputs that form the basis for further refinement.

3.2 Morphological Analysis

Morphological analysis is a systematic approach that decomposes a design problem into discrete functional parameters, each having multiple possible solutions. By constructing a morphological diagram (or matrix or chart), designers explore all possible combinations of functional solutions, potentially uncovering novel configurations (Ullman 2020). This technique is especially beneficial for physical systems with modular or hierarchical structures. It allows controlled exploration without overwhelming designers with unmanageable complexity.

3.3 TRIZ (Theory of Inventive Problem Solving)

Developed by Altshuller (1999), TRIZ (Theory of Inventive Problem Solving) is a robust, theory-driven method that analyzes patterns of innovation across patents and industrial inventions. It provides a contradiction matrix and 40 inventive principles to systematically resolve technical conflicts, making it particularly useful when conventional brainstorming stalls. TRIZ encourages designers to transcend typical trade-offs by identifying inventive solutions that overcome conflicting requirements.

3.4 Physical and Functional Decomposition

Physical decomposition splits a product (assembly) into its sub-assemblies and components. This helps in understanding the product architecture and interfaces between components. Functional decomposition breaks a system into its fundamental functions, which can be ideated on independently before recombining into full solutions (Dieter and Schmidt 2013). This modular thinking supports parallel development and facilitates problem understanding, helping to isolate challenging subproblems and focus ideation efforts effectively.

3.5 Analogical Reasoning

Analogical reasoning leverages solutions from disparate domains to inspire innovation, often leading to radical breakthroughs. Biomimicry (where biological systems inspire engineering solutions) is a prominent example (Goel and Bhatta 2004). Effective analogies typically come from fields unrelated to the current problem, encouraging fresh perspectives and expanding the design space.

3.6 SCAMPER

SCAMPER is a mnemonic that prompts designers to think about substituting, combining, adapting, modifying, putting to other uses, eliminating, or reversing elements of existing designs (Eberle 1972). It is particularly useful for improving or refining products by shifting perspectives and avoiding design fixation.

3.7 Visual Ideation Methods: C-Sketch and 6-3-5 Method

Visual ideation techniques enhance creativity by externalizing ideas through sketches. The C-Sketch method involves iterative sketching and passing ideas among team members for refinement (Rohrer 1969). The 6-3-5 method involves six participants each writing three ideas every five minutes, promoting rapid and collaborative idea expansion

(Rohrbach 1969). These methods leverage visual cognition to stimulate new concept combinations and cross-pollination.

3.8 Design Heuristics

Design heuristics are empirically derived cognitive prompts extracted from patent analyses and expert designers' behaviors (Yilmaz et al 2016). They serve as generative rules-of-thumb that stimulate idea fluency and diversity, particularly for novices. The heuristics are typically presented as cards containing prompts such as "Combine functions" or "Change orientation," supporting structured creativity while aligning with engineering constraints.

4. Computer-Aided Concept Generation

The rapid evolution of digital technologies has significantly impacted the concept generation phase, introducing powerful tools that augment human creativity and enable more extensive exploration of design alternatives. Computer-aided concept generation integrates computational methods, knowledge databases, and generative algorithms to support engineers in producing innovative and feasible concepts efficiently. Computer-Aided Product Design (CAPD), outlined in Figure 2, refers to the use of digital tools and software to create, analyze, and refine product designs. It plays a crucial role in modern engineering and manufacturing by improving efficiency, reducing errors, and accelerating the product development cycle (Fenves et al 2005).

4.1 CAD-Based Sketching and Visualization Tools

Computer-Aided Design (CAD) platforms have evolved beyond detailed modeling into tools that assist early-stage ideation through rapid sketching, parametric variation, and visualization. Software such as Autodesk Fusion 360, SolidWorks, and Siemens NX allow designers to quickly iterate on shapes, assemblies, and layouts, providing immediate feedback on spatial relationships and manufacturability. These visual aids improve communication within the design team (and other departments) and reduce misinterpretation of concepts, facilitating smoother transitions to detailed design.

4.2 Generative Design Platforms

Generative design employs algorithmic approaches where designers specify goals, constraints, and performance criteria, and the software autonomously generates optimized design alternatives (Ferreira & Leitão 2015). Platforms like Autodesk's Generative Design and nTopology (or nTop) use topology optimization, evolutionary algorithms, and machine learning to explore vast design spaces that would be infeasible manually. These tools excel in producing lightweight, structurally efficient, or multifunctional geometries, particularly valuable in aerospace, automotive, and biomedical engineering.

4.3 Knowledge-Based Systems and Case Libraries

Leveraging prior design knowledge and historical cases accelerates ideation by providing analogical inspiration and reuse opportunities. Knowledge-based systems integrate curated databases of past solutions, patent information, and engineering heuristics to suggest relevant concepts based on problem attributes (Gero and Maher 2013). For example, tools like KnowSim and Design Assistant support retrieval and adaptation of analogous designs, reducing redundancy and fostering innovation through recombination.

4.4 AI and Machine Learning

AI (Artificial Intelligence) and machine learning have begun to influence concept generation by identifying patterns, predicting promising solution paths, and assisting in creativity augmentation. Natural language processing (NLP) enables the mining of technical literature and patent databases for idea extraction, while reinforcement learning algorithms can guide iterative improvement of concept parameters [Quanz et al 2020]. Although still emerging, AI integration promises to shift ideation from purely human-driven toward collaborative human-AI creativity.

4.5 Digital Collaboration Platforms

Modern design environments increasingly support distributed teams through cloud-based platforms like Miro, Mural, and FigJam, which incorporate digital whiteboards, sketching tools, and design heuristics card decks (Miro 2025).

These platforms facilitate synchronous and asynchronous ideation, integrating structured prompts with visual tools to enhance group creativity even in remote settings.

4.6 Benefits and Limitations

Computer-aided concept generation enhances ideation by increasing speed, expanding the explored solution space, and improving accuracy in feasibility assessment. However, challenges include the learning curve for complex software, potential over-reliance on automated outputs leading to reduced human creativity, and difficulties in integrating diverse tools into cohesive workflows (Chakrabarti 2020). Moreover, computational methods often require well-defined constraints and objectives, which may not be fully available in early, ambiguous design stages.

5. Evaluation and Refinement of Concepts

The evaluation and refinement stage is critical in the conceptual design phase, transitioning from divergent idea generation to convergent selection and optimization of feasible solutions. Effective concept evaluation ensures that designs meet multiple criteria such as functionality, cost, manufacturability, sustainability, and risk tolerance, ultimately improving product success and reducing costly redesigns.

5.1 Purpose and Importance of Concept Evaluation

Concept evaluation serves to systematically reduce a broad set of ideas to a manageable number of viable options for detailed design and development. It balances competing criteria, mitigates subjective biases, facilitates stakeholder alignment, and supports traceability of design decisions (Ullman 2020). By applying structured methods, teams can transparently justify selections and identify trade-offs early, minimizing risks associated with uncertainty and incomplete information (Dieter and Schmidt 2013). Some of these techniques are briefly discussed below.

5.2 Common Concept Evaluation Techniques

Pugh Decision Matrix

Introduced by Stuart Pugh (1991), the Pugh matrix is a qualitative, comparative evaluation tool that ranks alternatives against a baseline or datum design using simple symbols (+, 0, –). This method encourages discussion, visualizes strengths and weaknesses, and provides a rapid way to shortlist concepts. However, the qualitative nature can introduce subjectivity and may not capture the relative importance of criteria.

Weighted Scoring Method (WSM)

Weighted Scoring Method (WSM), or Weighted Decision Matrix, extends evaluation rigor by assigning weights to criteria reflecting their importance and rating each alternative numerically (Dieter and Schmidt 2013). The total weighted scores provide a quantitative ranking. WSM offers flexibility and is widely used in industry due to its transparency. Nevertheless, it assumes linearity and can be sensitive to weight assignment and score normalization.

Analytic Hierarchy Process (AHP)

Developed by Saaty (1980), AHP decomposes decision problems into hierarchical structures of goals, criteria, and alternatives, employing pairwise comparisons to derive weights and preferences. It can handle qualitative and quantitative data, providing consistency checks and sensitivity analysis. AHP is suitable for complex, multi-criteria scenarios but requires more effort and decision-maker training.

TOPSIS

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is a widely used multi-criteria decision-making (MCDM) approach that ranks alternatives based on their geometric distance from an ideal solution.

It identifies the option closest to the ideal (best possible) solution and farthest from the negative-ideal (worst) solution, making it effective for complex decision problems involving conflicting criteria.

Go/No-Go Screening
This method eliminates alternatives that fail mandatory requirements or thresholds (safety, regulatory compliance, budget limits) at an early stage (Ullman 2020). It reduces the number of options before detailed evaluation, lowering cognitive load and focusing resources on viable concepts.

Risk-Informed Evaluation
Incorporating risk analysis into concept evaluation accounts for uncertainties in cost, performance, and schedule. Techniques such as risk matrices, fuzzy logic, or Monte Carlo simulations (Qamar et al 2008) help quantify and compare risk exposure among alternatives (Hazelrigg 1998). This approach is essential in safety-critical domains such as aerospace or medical devices.

5.3 Best Practices in Concept Evaluation

Based on the authors' long years of teaching product design and supervising design projects, some of the best practices in concept evaluation are mentioned here, not necessarily in any order of preference. (a) Engage cross-disciplinary teams to represent diverse stakeholder viewpoints and criteria. (b) Use a combination of methods, for example, Pugh matrix for preliminary screening followed by WSM or AHP for detailed ranking. (c) Derive criteria weights through consensus or data-driven approaches rather than arbitrary assignment. (d) Conduct sensitivity analysis to understand how variations in weights or scores affect rankings, enhancing robustness. (e) Maintain detailed documentation of evaluation processes to support design reviews and audits (Ullman 2020).

5.4 Digital Tools for Concept Evaluation

Software such as MATLAB, Excel, Python libraries, and PLM systems (eg, Siemens Teamcenter, PTC Windchill) facilitate automated implementation of evaluation matrices, multi-criteria decision analysis (MCDA), and risk assessments (PTC Windchill 2025). Integrating evaluation with simulation and modeling in multidisciplinary design optimization (MDO) frameworks enables more informed decision-making under uncertainty. Of course, this requires availability and knowledge of these digital techniques.

6. Challenges, Best Practices, and Integration

Concept generation and evaluation in product design are inherently complex and multidisciplinary activities that face several challenges. Recognizing these challenges and implementing best practices are essential for effective integration of these processes into engineering workflows, thereby enhancing design outcomes and innovation. The major ones are briefly discussed below.

6.1 Challenges in Concept Generation and Evaluation

One of the major challenges in concept generation is overcoming cognitive biases and mental fixation, which limit creativity by constraining designers to familiar solutions (Jansson and Smith 1991). Designers may get fixated on initial ideas, reducing the diversity and novelty of concepts explored [Dane and Pratt 2007.

Another challenge is managing the balance between creativity and feasibility. While generating a broad set of concepts encourages innovation, it can also lead to an overwhelming number of alternatives, complicating the evaluation and selection process. Efficient filtering and prioritization for only feasible and practically viable solutions are needed to handle this complexity.

In the evaluation phase, subjectivity and inconsistency in criteria weighting and scoring pose significant risks to decision quality (Liu and Hai 2013). Additionally, integrating qualitative user preferences with quantitative technical metrics remains difficult, often resulting in oversimplified models that fail to capture real-world trade-offs (Chakrabarti et al 2011).

Finally, integration of concept generation and evaluation tools within organizational workflows and digital platforms can be hindered by lack of standardization and interoperability (Jiao and Tseng 2010). This limits the seamless flow of information and collaboration among multidisciplinary teams (such as from the design, manufacturing, planning, and business management teams).

6.2 Lack of Creative Product Design Courses

Many universities, particularly in engineering and technology programs, lack dedicated courses that emphasize creative product design and ideation, leading to a gap in students' ability to generate innovative solutions (Qamar et al 2016). Traditional curricula often prioritize analytical and technical skills over divergent thinking and human-centered approaches, which are essential for design innovation (Dym et al 2005). For instance, in a Mechanical Engineering program, there would generally be a course on Design of Machine Elements, but not a course on Design Methodology or Creative Design of Products. As a result, students may graduate with strong theoretical knowledge but limited capacity for creative problem-solving, especially targeted at design improvement (redesign) of existing products, or design of new products. Studies have highlighted the need for integrating structured creativity and design thinking into engineering education to foster innovation and prepare students for complex, real-world challenges (Sheppard et al 2009; Liedtka 2015). Without such exposure, future designers risk defaulting to incremental improvements rather than breakthrough innovations (Al Jahwari et 2022).

6.3 Best Practices for Effective Concept Generation and Evaluation

To address cognitive fixation, structured creativity techniques such as TRIZ, morphological analysis, and reasoning by analogy have been shown to significantly enhance idea diversity and originality [Altshuller 1999; Cross 2008]. Encouraging cross-functional teamwork and diversity of perspectives further mitigates mental biases [Paulus and Nijstad 2003].

Establishing clear, measurable criteria early in the design process is critical for meaningful evaluation. Use of standardized criteria frameworks and multi-criteria decision analysis (MCDA) methods improves transparency and repeatability of selection decisions [Belton and Stewart 2002]. Engaging all stakeholders (including major customers) actively in criteria definition ensures alignment with user needs and business goals (Loosemore et al 2016).

Incorporating iterative feedback loops between concept generation and evaluation phases fosters continuous refinement and reduces risks associated with premature decisions (Ullman 2020). Rapid prototyping and simulation tools help validate concepts early, enabling evidence-based selection (Thomke and Reinertsen 1998).

Finally, integrating concept generation and evaluation tools into product lifecycle management (PLM) and collaborative platforms enhances knowledge sharing, version control, and traceability, thereby supporting effective teamwork and decision documentation (Jiao and Tseng 2010).

6.4 Integration of Concept Generation and Evaluation

Successful integration demands interoperable tools and data standards that enable smooth transition from concept generation to selection and detailed design. Recent advances in digital engineering, such as model-based systems engineering (MBSE), provide frameworks to link conceptual design artifacts with downstream analyses and manufacturing considerations (Friedenthal et al 2015).

Machine learning and artificial intelligence are increasingly being explored to automate aspects of concept evaluation by learning from historical data and predicting concept performance under uncertainty [Benedettini et al 2019]. These technologies promise to augment human decision-making, reduce evaluation time, and uncover hidden patterns. Moreover, integration requires cultural and organizational alignment to promote open communication, shared understanding, and collaborative decision-making across disciplines (Dorst 2015). Training and change management play crucial roles in embedding concept generation and evaluation as integral parts of the engineering design process.

7. Conclusions

Concept generation and evaluation are foundational pillars of effective product design, playing a decisive role in translating market needs and technical requirements into viable engineering solutions. This paper provides a comprehensive overview of structured techniques for generating innovative concepts, from creative heuristics and systematic methods to computer-aided tools, as well as robust methods for evaluating and selecting the best concepts. The reviewed multi-criteria decision-making approaches such as AHP, TOPSIS, and weighted scoring models facilitate transparent, objective, and repeatable concept selection processes. Methods like the Pugh matrix enable quick screening, while utility theory and economic evaluation incorporate stakeholder preferences and financial considerations into decision-making. Each method offers distinct strengths and limitations, underscoring the need for judicious selection and often hybrid approaches tailored to specific design contexts.

Despite advances in methodology and software integration, challenges remain including cognitive biases, complexity management, and the effective integration of qualitative and quantitative data. Best practices such as structured creativity techniques, early stakeholder engagement, iterative evaluation loops, and integration with product lifecycle management systems enhance the effectiveness and efficiency of concept generation and evaluation. Emerging trends in digital engineering, including model-based systems engineering and artificial intelligence, promise to further revolutionize concept evaluation by enabling predictive analytics, automation, and enhanced collaboration. However, successful adoption depends on organizational culture, interdisciplinary communication, and continuous learning.

In conclusion, a systematic and well-integrated approach to concept generation and evaluation is essential to fostering innovation and ensuring that product designs meet technical, economic, and user requirements. Future research should focus on developing adaptive, AI-augmented decision support tools and standardized integration frameworks to address current challenges and unlock new potentials in engineering design.

Acknowledgements

The authors wish to acknowledge the support of Sultan Qaboos University in all academic and research matters.

References

Al Jahwari, F., Qamar, S. Z., Pervez, T., and Al Maskari, N., “Using CDIO Principles for Teaching of Mechanical Design Courses,” *IEEE Global Engineering Education Conference (EDUCON)*, Tunis, Tunisia, pp. 1683–1688, 2022. https://doi.org/10.1109/EDUCON52537.2022.9766735

Altshuller, G., *The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity*, Technical Innovation Center, 1999.

Arif, A. F. M., Sheikh, A. K., Qamar, S. Z., and Al-Fuhaid, K. M., “Modes of die failure and tool complexity in hot extrusion of Al-6063,” *Proceedings of the 16th International Conference on Production Research (ICPR-16)*, Prague, Czech Republic, 2001.

Belton, V., and Stewart, T. J., *Multiple Criteria Decision Analysis: An Integrated Approach*, Springer, 2002.

Benedettini, O., Neely, A., and Swink, M., “Why do servitized firms fail? A risk-based explanation,” *International Journal of Operations & Production Management*, vol. 39, no. 3, pp. 324–344, 2019. https://doi.org/10.1108/IJOPM-12-2017-0732

Chakrabarti, A., Blessing, L., and Wallace, K., *An Approach to Conceptual Design*, Springer, 2011.

Chakrabarti, A., *Computational Support for Engineering Creativity*, Springer, 2020.

Chrysikou, E. G., and Weisberg, R. W., “Following the wrong footsteps: Fixation effects of pictorial examples in a design problem-solving task,” *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 31, no. 5, pp. 1134–1148, 2005. https://doi.org/10.1037/0278-7393.31.5.1134

Cooper, R. G., *Winning at New Products: Creating Value Through Innovation*, 4th ed., Basic Books, 2017.

Cross, N., *Engineering Design Methods: Strategies for Product Design*, Wiley, 2008.

Daly, S., Yilmaz, S., Christian, J., and Gonzalez, R., “Design heuristics in engineering education: A pilot study,” *ASME International Design Engineering Technical Conferences*, 2012.

Dane, E., and Pratt, M. G., “Exploring intuition and its role in managerial decision making,” *Academy of Management Review*, vol. 32, no. 1, pp. 33–54, 2007. https://doi.org/10.5465/amr.2007.23463682

Dieter, G. E., and Schmidt, L. C., *Engineering Design*, 5th ed., McGraw-Hill, 2013.

Dorst, K., *Frame Innovation: Create New Thinking by Design*, MIT Press, 2015.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., and Leifer, L. J., “Engineering design thinking, teaching, and learning,” *Journal of Engineering Education*, vol. 94, no. 1, pp. 103–120, 2005. https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

Eberle, B., *SCAMPER: Games for Imagination Development*, DOK Publishers, 1972.

Fenves, S. J., Sriram, R. D., Subrahmanian, E., and Rachuri, S., “Product information exchange: practices and standards,” *Journal of Computing and Information Science in Engineering*, vol. 5, no. 3, pp. 238–246, 2005. https://doi.org/10.1115/1.2013289

Friedenthal, S., Moore, A., and Steiner, R., *A Practical Guide to SysML: The Systems Modeling Language*, Morgan Kaufmann, 2015.

Gero, J. S., and Maher, M. L., *Modeling Creativity and Knowledge-Based Design*, Routledge, 2013.

Goel, A. K., and Bhatta, S. R., "Use of design patterns in analogy-based design," *Advanced Engineering Informatics*, vol. 18, no. 2, pp. 85–94, 2004. https://doi.org/10.1016/j.aei.2004.09.003

Hazelrigg, G. A., "A framework for decision-based engineering design," *Journal of Mechanical Design*, vol. 120, no. 4, pp. 653–658, 1998. https://doi.org/10.1115/1.2829328

Jansson, D. G., and Smith, S. M., "Design fixation," *Design Studies*, vol. 12, no. 1, pp. 3–11, 1991. https://doi.org/10.1016/0142-694X(91)90003-F

Jiao, J., and Tseng, M. M., "Design for mass personalization," *CIRP Annals*, vol. 59, no. 1, pp. 175–178, 2010. https://doi.org/10.1016/j.cirp.2010.03.097

Kroll, E., Qamar, Z., and Mohammad, R., "A high-level product representation for automatic design reasoning," *ASME Conference Proceedings*, 1994.

Liedtka, J., "Perspective: Linking design thinking with innovation outcomes through cognitive bias reduction," *Journal of Product Innovation Management*, vol. 32, no. 6, pp. 925–938, 2015. https://doi.org/10.1111/jpim.12263

Liu, Y., and Hai, Y., "An improved fuzzy AHP method for multi-criteria decision making," *Applied Mathematical Modelling*, vol. 37, no. 2, pp. 922–932, 2013. https://doi.org/10.1016/j.apm.2012.03.027

Loosemore, M., Raftery, J., Reilly, C., and Higgon, D., *Risk Management in Projects*, Routledge, 2016.

Miro, "Online Collaborative Whiteboard Platform," 2025. [Online]. Available: https://www.miro.com

Nebulem, "Product Design: What is Product Design? An Introduction," 2025.

Osborn, A. F., *Applied Imagination: Principles and Procedures of Creative Problem-Solving*, Scribner, 1953.

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K.-H., *Engineering Design: A Systematic Approach*, Springer, 2007.

Paulus, P. B., and Nijstad, B. A., *Group Creativity: Innovation Through Collaboration*, Oxford University Press, 2003.

PTC, "Windchill Product Lifecycle Management," 2025. [Online]. Available: https://www.ptc.com/en/products/plm/windchill

Pugh, S., *Total Design: Integrated Methods for Successful Product Engineering*, Addison-Wesley, 1991.

Qamar, S. Z., "Engineering Education: Skill Levels and Outcome-Based Approach," *International Journal of Management and Applied Science*, vol. 4, no. 12, pp. 25–29, 2018.

Qamar, S. Z., Al-Abri, O., Al-Kharusi, M., and Qamar, S. B., "How to Address Sustainability in a Mechanical Engineering Program — Implementation and Challenges," *ASEE Annual Conference and Exposition*, 2023.

Qamar, S. Z., Al-Maskari, N., and Pervez, T., "Integrating Sustainability into Engineering Education: Implementation and Challenges," *2nd GCC International Conference on Industrial Engineering and Operations Management (IEOM)*, Muscat, 2024.

Qamar, S. Z., Arunachalam, R., and Qamar, S. B., "A Critical Thinking Paradigm for Materials and Manufacturing Education," *ASEE Annual Conference and Exposition*, 2021.

Qamar, S. Z., Hinai, N., and Qamar, S. B., "Assessment of Critical Thinking Skills in Engineering Education," *ASEE Annual Conference and Exposition*, 2022.

Qamar, S. Z., Pervez, T., Al-Maskari, N., and Qamar, S. B., "Creativity and Innovation in Engineering: A Brief Review and Roadmap for the Future," *ASEE Annual Conference and Exposition*, 2025.

Qamar, S. Z., Ramanathan, A., and Al-Rawahi, N. Z., "Teaching product design in line with Bloom's taxonomy and ABET student outcomes," *IEEE Global Engineering Education Conference (EDUCON)*, pp. 1017–1022, 2016. https://doi.org/10.1109/EDUCON.2016.7474653

Qamar, S. Z., Sheikh, A. K., Arif, A. F. M., Younas, M., and Pervez, T., "Monte Carlo simulation of extrusion die life," *Journal of Materials Processing Technology*, vol. 202, no. 1–3, pp. 96–106, 2008. https://doi.org/10.1016/j.jmatprotec.2007.09.039

Quanz, B., Sun, W., Deshpande, A., Shah, D., and Park, J., "Machine learning based co-creative design framework," *arXiv preprint arXiv:2001.08791*, 2020.

Rohrbach, B., "Kreativ nach Regeln – Methode 635," *Absatzwirtschaft*, vol. 12, no. 19, pp. 73–75, 1969.

Rohrer, D. C., "Creative Sketching and Design," *Design Studies*, 1969.

Sheppard, S., Macatangay, K., Colby, A., and Sullivan, W. M., *Educating Engineers: Designing for the Future of the Field*, Jossey-Bass, 2009.

Thomke, S., and Reinertsen, D., "Agile product development: Managing development flexibility in uncertain environments," *California Management Review*, vol. 41, no. 1, pp. 8–30, 1998.

Ullman, D. G., *The Mechanical Design Process*, 6th ed., McGraw-Hill Education, 2020.

Ulrich, K. T., and Eppinger, S. D., *Product Design and Development*, 7th ed., McGraw-Hill Education, 2020.

Yilmaz, S., Seifert, C. M., and Gonzalez, R., “Design heuristics in engineering idea generation,” *Journal of Engineering Education*, vol. 105, no. 4, pp. 594–620, 2016. https://doi.org/10.1002/jee.20135.