8. The mutual impact of contemporary challenges and design transitions: perspectives on product development

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The brief history of industrial design has witnessed several turns during its evolution. A long time has passed since design was about finding the correct language for machine-made mass products, and balancing the form with the function. In those times, the debate was about the role of designers in a world that was optimistic about progress and keen to believe the most significant design impact would be to drive innovation. In a few decades, design gained world-wide recognition for its effectiveness in helping businesses succeed by interpreting new technology in user-friendly ways, adding value, and successfully communicating it. During this time, designers and researchers made efforts to represent the process applied in design to develop new products, and such representations helped define the discipline approach, reflect on it, and explain it to others. These efforts evolved and diversified into many versions, but today, no single scheme is agreed upon and shared by the design community. Yet, looking at their evolution, it is possible to see how they developed with the discipline and adapted to change. Indeed, designers widened their work's scope and started to question its meaning and impact on a larger scale, involving people and communities, aiming at social innovation, setting sustainable goals, and transitioning into new design approaches. While the awareness of being part of a larger scheme is not new, the urgency of today's challenges is affecting he whole design community. From this perspective, the design process should reflect the mutual impact of contemporary challenges and design transitions. This paper describes an overview of the design process representations from an evolutionary perspective, focussing on product development. An insight into the phases of the design process is offered to see where the newest technologies – AI in particular – are merging with design and, possibly, collaborating through the transition.

8.1 The evolution of design process models

While the history of industrial design goes back to the development of new skills and professions necessitated by the Industrial Revolution, design as an academic discipline has gained recognition in the last 50 years. To reach such a step, scholars researched and developed concepts of design methodology to formalise industrial design into a scientific discipline (Archer, 1979; Cross *et al*., 1981; Schön, 1983; Bürdek, 2005). One of the outcomes was to represent and formalise the industrial design approach into a model of its process, as by Archer (1968), Schön (1983), Bathany (1996), Valkenburg and Dorst (1998), and Cross (2000), to mention a few. The references can be traced back to the '60s when several models were created. The first model series referred to the product development process typical of industrial manufacturing companies. These were derived from engineering models and presented a structure of consecutive phases, passing through which it was possible to make a new industrial product.

Later, design started to widen its application field, including areas such as human-computer interaction, business strategies, private and public services, and new approaches such as user-centred design and participatory design. The representation of the design process started to emphasise the iterations of the design phases – by cyclical structures and extra phases.

Also, starting in the '90s, design organisations and design consultants mainly developed their representations to explain what design is, what value would be added to a company's business, and what outcomes to expect. Some of those models have also been adopted primarily in the academic context, such as the Double Dimond by the Design Council (2004) and others by the design consultants IDEO (2008, 2012) and Frog (Bobbe *et al*., 2016).

The literature review shows that a tension exists between analysis and synthesis in all models. In various models, analysis involves breaking the problem into parts – a divergent process of dividing it into sub-problems. Meanwhile, synthesis entails reassembling these parts in a new way – a convergent process that moves from details to the general (Cross, 1984; Banathy, 1996). However, this can also be the opposite, where analysis leads to agreement and convergence, while synthesis is developed into greater detail and divergence. Nigel Cross (2021) suggests that the design process is predominantly convergent but punctuated by periods of divergence. One interesting notion is that researchers applying a scientific process separate analysis from synthesis, while several design models merge analysis with synthesis since designers tend to diverge and reframe problems while solving them (Akin, 1986; Dubberly, 2004).

The academic debate about design processes is lively and demonstrates a considerable interest. In this chapter, a limited collection of the models is organised as a timeline (Figure 1). The formation of the timeline is based on the literature review, in which three publications were instrumental: Dubberly's (2004) collection of over 100 models developed from 1964 to 2004; the comparison of design process models from academic theory and professional practice (Bobbe *et al*., 2016); and a study of models as metaphors in the educational context (Bravo and Bohemia, 2021). The scope of the timeline is not to present a complete list but to show a selection representing the main aspects of the evolutionary path of design process models.

Dubberly's collection clusters the models in *Academics Consultant*, *Software development*, *Complex linear models*, and *Cyclic models*; thus, it mixes the context of development (academic consultant, etc.) with the structure (linear, cyclic, etc.). Such an approach does not facilitate the generalisation of understanding, although the collected works are rich and valuable for anyone approaching the subject.

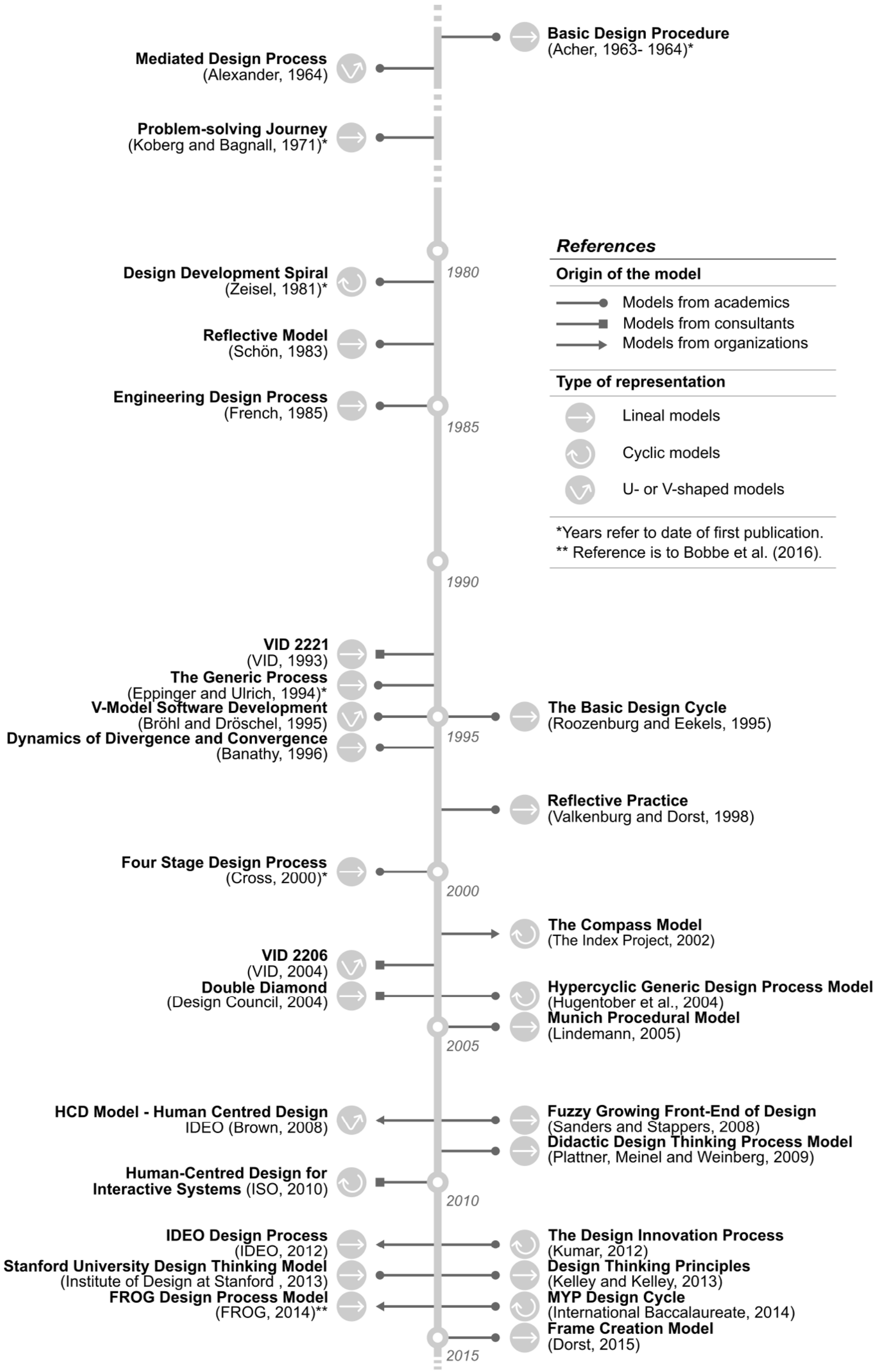

Figure 1.
Timeline of design process models.

Bobbe, Krzywinski, and Woelfel (2016) aimed to identify a typical structure from different design process models focussing on industrial and engineering design and comparing models from academia, professional organisations, and design consultants. This way, they point out the heterogeneous input and interest in the subject. Such a different origin is highlighted in the timeline, too. The study of Bravo and Bohemia develops metaphors to explore the models and their use in design education. However, this chapter focusses on their collection of models rather than on the metaphors, cf. 8.2.

By looking at the evolution of the models, it is possible to notice that there are common structures and graphical notations as described below.

The first generation, prominent until the 2000s, was characterised by linear and rational models, often represented as mathematical procedures. These models involved an input, a transformation process, and an output. Over time, these processes became more detailed, adding phases and associating them with activities and methods. These processes emphasise progression and incorporate phases that might be iterative but subordinate.

In other cases, linear models are shaped into V or U models where the phases follow a path with the form of such letters. They highlight the iteration among phases of the two sides of the process (i.e., VDI 2004).

Later, circular or cyclic models were developed for human-centred design for interactive systems (i.e., ISO 2010) and spread to other fields. Cyclic representations emphasise the iterative nature of design processes.

Similarly, spiral models are like cyclic models, where the process repeats a series of activities at different levels of the design process, showing a progression. Both cyclic and spiral models highlight the presence of feedback loops, tests, and evaluation phases that aim to improve the result. Although some of these models appeared in early design history, most were developed from the '90s and flourished in the early 2000s.

Nevertheless, it must be noted that the development of new structures does not imply the disappearance of previous ones. Indeed, most new models are still linear with extra details, such as steps, gates, etc.

In the timeline, design organisation and consultant models started to be formalised in the '00s, when academic ones also increased – this progression and increase of models aligned with design developing as a practice and discipline. On the one hand, it highlights the professionals' need to communicate their expertise to stakeholders involved in the process. On the other hand, it shows the scholars' work in developing synthetic representations that are useful in education and research. Furthermore, the specialisation of models such as *human-centred design*, *design thinking*, or *service design* models, highlights the developing of new areas of design application in line with the evolution of the discipline.

Indeed, while design process models in academia focus on formulating, validating, and assisting students in understanding the design process and guiding them through the project, changes in business organisations and services offered by companies have led to the creation of models to communicate and illustrate their approaches:

> **[…] As a recent phenomenon, many design studios changed their operative scope to full-service from analysis and ideation to detailing, modelling and production planning, at the same time offering hardware, software and service design from a single provider. Since the portfolio of these companies has diversified, it becomes relevant to explain the competencies and practices (Bobbe *et al*., 2016, p. 1206).**

A further in-depth survey would be necessary to validate the timeline, which suggests some preliminary observations: in the last decade, no new models have reached widespread popularity, and those that are available do not have specific new features to face today's challenges. These traits might depend on whether the timeline collects product/industrial design process models or does not analyse them in depth. So, further investigation could be conducted in other design domains, or the selected models could be examined more deeply. In this chapter, the second approach is presented, along with a description of the phases of the design processes. Such a study allowed a comparison of the models beyond their structures (linear, cyclic, etc.).

8.2 The phases of design process models

Looking at the design process models in detail, it is clear that all of them are articulated in phases that represent a progression, sometimes including loops, gates, and dynamically diverging and converging phases. However, even if those phases are organised in different structures (linear, cyclic, etc.), they can all be reconstructed into a linear sequence of four/five phases. Indeed, Bobbe, Krzywinski, and Woelfel (2016) compared a set of process models based on a linear reference structure. They fit fifteen models (4 by academics, 5 by organisations, 6 from consultants) in a linear sequence of five phases: Analyse, Define, Design, Finalise and Implement. From their reading, all design process models appear to have at least the first four steps in common. Indeed, those that do not need to include the Implementation phase are mostly academic ones. Bravo and Bohemia (2021) also analysed ten design process models and synthesised them in four phases: Observe, Interpret, Ideate/explore, and Implement. In their study, they focussed on the adaptation of the models in design education. For that context, they added two subsequent phases: Evaluate/Improve and Share.

The two systems are shown in Table 1. The naming might be confusing; for instance, *implement* appears in the fourth and third phases. Different names are given to phases with similar activities in the process. For clarity, a renaming for the four phases is proposed:

1. The Research phase includes all designers' activities to understand the user and context. Here, designers are *observers*. It is a divergent phase aimed at gathering data, understanding the users, and discovering new paths.
2. The Definition phase requires analysis and synthesis of the collected information to formulate a design proposal. In this case, designers are *interpreters*. Here, the methods enable convergence toward a solution.
3. In the Development phase, designers ideate several solutions and test them in a very iterative process that diverges again from the design definition towards many possibilities. Here, designers are *creators*.
4. In the Delivery phase, designers converge on a final design

and detail it for realization. Here, synthesis is where designers are *achievers*, using methods and tools to make their ideas real.

The synthetic list of phases represents the essence of the design process: a path to find innovative solutions through a series of activities that inform and activate the following ones until reaching the realisation. The design models are valuable tools for communicating among people of the same community to be aligned on their work, to communicate to others the role of design, and to teach students different design approaches.

Such a synthetic representation of the design process helps take an extra step in the analysis. That is, to investigate the consolidated methods used in each phase by designers to reach their goal and check for new contemporary methods that represent the latest way designers are tackling today's challenges.

Phases	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
Bobbe et al. (2016)	Analyse	Define	Design	Finalise	Implement	
Bravo and Bohemia (2021)	Observe	Interpret	Ideate/ Explore	Implement	Evaluate/ Improve	Share
Proposed naming	**Research**	**Definition**	**Development**	**Deliver**		

Table 1.
Synthesis of the list of phases.

8.3 The methods used in phases of product design

From the literature review, a limited selection of references focussed on product development. The methods mentioned by four authors were collected (Kumar, 2012; Ulrich and Eppinger, 2016; Cross, 2021, Isgrò, 2021) and organised in the four phases of the design process (Table 2). Each author presents a similar distribution of methods across the various stages. In the table the methods are distributed among the four phases and clustered by scope (observation, user, research, context research, mapping, definition, idea generation, project representation, project development evaluation, and communication).

Looking through the list of methods, a few aspects of each phase are of particular notice.

The Research phase presents the most significant number of methods. This stage supports analysis and has a divergent nature that contains methods adopted and adapted from other disciplines, such as ethnographic interviews, focus groups, SWOT analysis, etc.

The Definition phase synthesises the previous research and thus focusses on analysing user research (personas, profiles, user journeys, etc.); mapping (includes matrixes and maps that facilitate decision-making); and defining (consists of all methods to converge towards a design brief).

The Development phase emphasises idea generation and project development while including some evaluation and communication methods. Here are the most typical methods of design, such as brainstorming, concept generation, prototyping and storyboards.

The Delivery phase is the least extensive in terms of the number of methods used. It focusses mainly on project development but also includes communication and evaluation.

Table 2 shows a decrease in the number of methods as the process progresses, with only a few methods for the Delivery phase. Therefore, as the design process progresses and converges, the diversity in methods also decreases.

In general, this list of methods shows the significant presence of tools for in-depth research that enable the users in the process and a mix of qualitative and quantitative data to be considered. Also, it shows how designers offer a large amount of expertise in areas ranging from analysis and creation to detailing, modelling, and production planning.

The collection of consolidated methods shows a lack of methods conceived to directly tackle today's complex and wicked problems. Most likely, it is necessary to step beyond this design area to find insights and proposals on the subject (cf. 8.5).

On the other hand, product design evolves with technological advancements, which influence how products are designed and manufactured, and includes updated tools and methods in the process. For instance, computer-aided programmes optimise many steps of the process and enable previously impossible shapes. Then, additive manufacturing techniques accelerate the process by anticipating the testing by working prototypes and, again, allowing new shapes that were previously impossible to make. Now, we are living with the advent of Artificial Intelligence and discovering what to do with it as it happens. Looking at it from an optimistic perspective, AI-enabled research and design methods might support the transition designers must make to tackle today's contemporary challenges. That is why understanding where AI will intervene in the design process is essential and must be widely investigated. This chapter provides insight into how AI-based methods (later called *tools*) are used in the design process phases from an evolutionary perspective in product development.

8.4 AI presence in product design process phases

Presented here are state-of-the-art AI-based tools mapped and organised in a four-phase design process (Isgrò *et al*., 2021) that has been recently updated (Croce, 2024). Although both studies offer interesting insights into how AI is being adopted in the design process, the focus here is limited to the number of methods and their distribution in the process.

Table 3 (Isgrò *et al*., 2021) maps the collected 37 tools, divided into two categories depending on the level of development: still in the research or prototype phase (29) or commercially available (8).

Table 4 (Croce, 2024) shows 66 commercially available tools. Some of these represent the evolution of tools still in their prototype phase in 2021.

Such a greatly increased number of tools to appear on the market in only a few years shows a massive implementation of AI in design. Also, from a comparison of the tables, it is noticeable that while most of the tools were used for the development phase, they are now largely present in the research and delivery phases.

The design process evolves quickly by adopting new methods (tools) in each phase. This phenomenon is ongoing, and extra study will be required to evaluate the mutual impact of AI-enabled methods in design practice and discipline. So far, AI appears to be blending into the typical design process model without the development of new models.

Research	***Definition***	***Development***	***Delivery***
Observation			
Field Visit	Observations to Insights		
Video Ethnography	Focus Group		
User Pictures Interview			
Experience Simulation			
Field Activity			
Observing product in use			
Etnography			
Shadowing			
Task Analysis			
People Objects			
Environments Menssages			
Services			
User research			
User scenarios	User profiles		
User trip	Personas		
Interest Groups	User Observations		
Discussion	Database		
Questionnaire	User Response Analysis		
Research Participant Map	User Observation		
Research Planning Survey	Database Queries		
Focus group	Compelling Experience Map		
Observe users in action			
Five Human Factors	Semantic Profile		
Ethnographic Interview	User Groups Definition		
Cultural Artifacts	User Journey Map		
Image Sorting	Persona Definition		
Remote Research	Customer Statements		
Study Customers	Focus Group		
Interview			
User Diaries			
Being your user			
Personas			
Empathy Map			
Context research			
Buzz Reports			
Popular Media Scan			
Key Facts			
Trends Expert Interview			
Keyword Bibliometrics			
Popular Media Search			
Publications Research			
Analogous Models			
Industry Diagnostics			
Consider Implications of Trends			
Imitate, but Better			
Product Segment Map			
Quantitative Surveys			
Trend Analysis			
Technology Research			
Historical Analysis			

Research	Definition	Development	Delivery
Mapping			
Innovation Sourcebook	Function analysis		
Value engineering	Trends Matrix		
Ten Types of Innovation Framework	Convergence Map		
Innovation Landscape	Initial Opportunity Map		
Eras Map	Offering-Activity-Culture Map		
Innovation Evolution Map	Insights Sorting		
Financial Profile	ERAF Systems Diagram		
Competitors	Entities Position Map		
Complementors Map	Costumer Journey Map		
Ten Types of Innovation Diagnostics	Symmetric Clustering Matrix		
Contextual Research Plan	Asymmetric Clustering Matrix		
Information Maps	Tree/Semi-Lattice Diagramming		
Product–Process Change Matrix	Activity Network		
Technology Roadmap	Insights Clustering Matrix		
User Research Plan	Summary Framework		
Mind Maps	Needs Statements		
	Descriptive Value Web		
	Venn Diagramming		
	Definition		
	Objective tree		
	Performance specification		
	Quality Function Deployment		
	Design brief		
	Intent Statement		
	Value Hypothesis		
	Mission Statements		
	Target Specifications		
	Costumer Requirements		
	Design Specifications		
Idea Generation			
From...To Exploration	Opportunity Mind Map	Brainstorming	
Compile Bug Lists		Synectics	
Follow a Personal Passion		Enlarging the search space	
Brainstorming		Concept Metaphors and Analogies	
Pull Opportunities from Capabilities		Ideation Session	
Mine Your Sources		Morphological chart	
		Role-Play Ideation	
		Ideation Game	
		Puppet Scenario	
		Foresight Scenario	
		Synthesis Workshop	
		Concept Generation	
		Moodboards	
		Visual and semantic confrontations	

Research	***Definition***	***Development***	***Delivery***
	Project representation		
Fast visualization		Concept Prototype Concept Sketch Concept Scenarios Partial/Full Product Representation	
		Project development	
	Design Principles Generation Analysis Workshop Principles to Opportunities Project Refinement Project Managment Project Spin-off Initial Technological Approach	Establishing the Architecture Concept Sorting Concept Grouping Matrix Morphological Synthesis Prescriptive Value Web Concept-Linking Map Final Specifications Behavioural Prototype Physical Prototyping Rapid Prototyping Multidisciplinary work Review and improvement Morphological Analysis	Solution Roadmap Material Selection Strategy Roadmap Platform Plan Product Life Cycle Strategy Plan Workshop Implementation Plan Competencies Plan Team Formation Plan Performance Capabilities Related System-Level Design Issues
	Evaluation		
SWOT Analysis Workshops with “multivoting” Web-based surveys Real-Win-Worth-it (RWW) Criteria Evaluating Fundamentally New Product Opportunities	Assessment Criteria Information Analysis Modeling and Simulation	Weighted objectives Concept-Generating Matrix Concept Evaluation Solution Prototype Solution Evaluation Screening matrix Concept Screening Concept Scoring Concept Testing Design Assumptions Check	Feedback loops Pilot Development and Testing Learning Experiences Product Performance Criteria
	Communication		
Storytelling	Reflect on the Results and the Process Scenarios	Concept Catalog Solution Diagramming Solution Storyboard Solution Enactment Solution Database Storyboard	Vision Statement Innovation Brief Storytelling Launch of outcome

Table 2.
Design Methods organised in the four phases of the Design Process.

The list of tools shows that only one (n. 66) responds to the new challenges. It can assist the designers in their decision-making to choose environmentally benign design parameters for products. Based on an Artificial Neural Network (ANN) model, it takes life-cycle design parameters (i.e., size of product, density of material, manufacturing process, transport mode, and recyclability) as inputs. It provides the corresponding outputs regarding a product's *carbon footprint* and *life cycle cost* (Singh and Sarkar, 2023).

Thus, it appears that the integration of AI is limited to improving design methods and does not support product designers in facing contemporary challenges.

8.5 Further developments

The overview of the design process models highlights that although different people developed new models during the past 50 years, they all have similar structures describable by a progression of typically four phases.

Also, the timeline shows that no new models have been broadly shared in the design community in the past decades if looking for product design processes. Only a detailed analysis of the process phases and methods showed innovative features. Indeed, it was possible to find, for example, only one the application of a new tool that integrates the Development phase, supporting the transitions toward sustainability. Such a study indicates one path for design processes and contemporary challenges to develop from mutual interaction.

Nevertheless, more extensive research could be necessary since the focus on the product design domain produced a collection of models not explicitly featured to tackle contemporary complex and wicked problems. However, such an investigation might still not be sufficient. Indeed, some scholars point out that:

> **Traditional design approaches […] were inadequate for addressing this class of problem. […] Areas of design focus such as service design, experience design, design for social innovation, deep design, meta-design, and various ecological and sustainable**

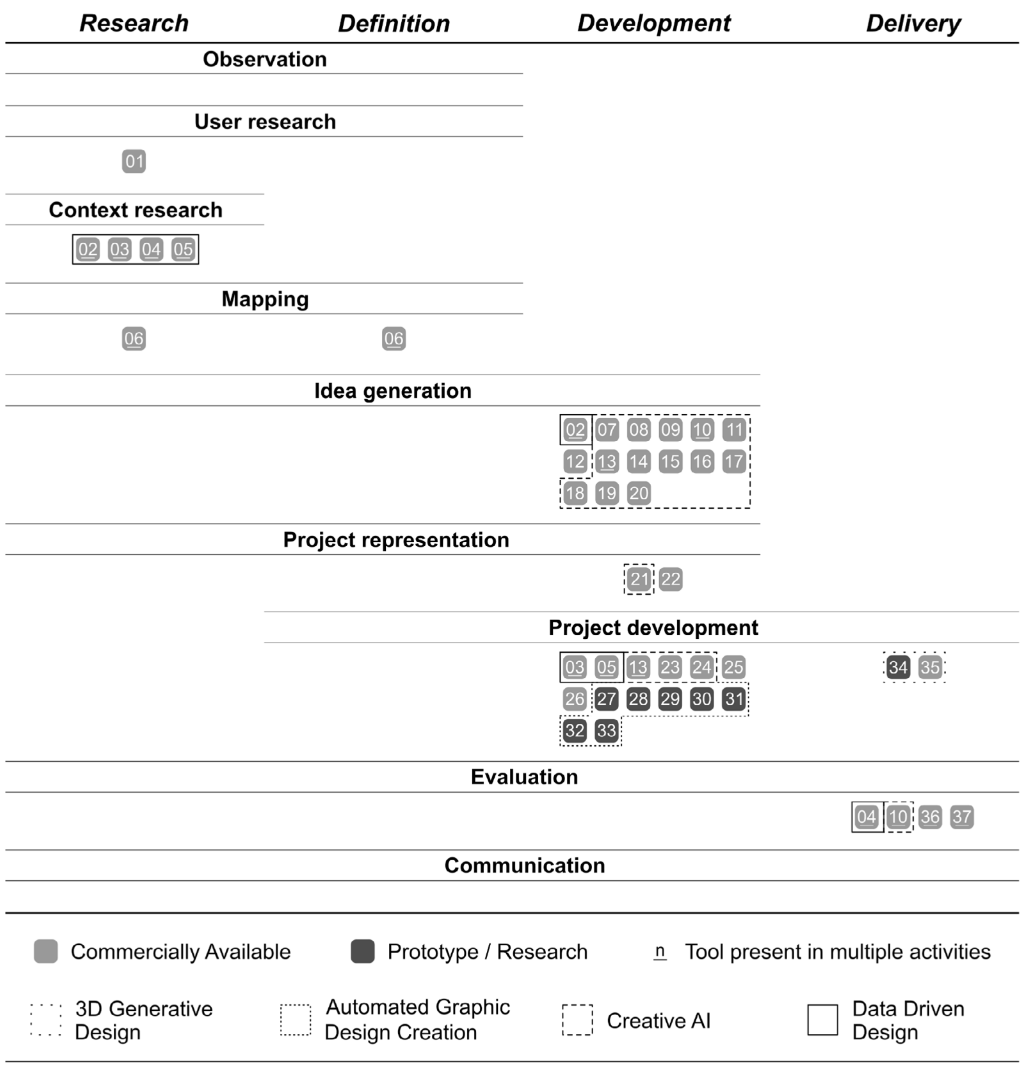

Table 3.
AI-based tools in the design process (adapted from Isgrò *et al*., 2021).

Activity	*Research*	*Definition*	*Development*	*Delivery*
Observation	01	52		
User research	02 03 04 05 06 07 08 12 09 10 11	09 10 11	09 10 11	
Context research	13 14			
Mapping	15 16 50	12 16 50		
Idea generation	17		10 17 18 19 20 21 22 23 24 25 26 27 28 29 30 39 51 52	
Project representation	15 16 50		31 32 33 63	
Project development			20 25 26 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 66	52 54 55 56 57 58 60 61 62 63 64 65 59 66
Evaluation		61	52	58 61 33 64
Communication	26 34 36 39 43 50	34 36 39 43 50	34 35 37 39 43 50 26	25 26 31 32 34 35 36 37 38 39 42 43 44 46 47 48 49 50

Commercially Available — Prototype / Research — n Tool present in multiple activities

3D Generative Design — Automated Graphic Design Creation — Creative AI — Data Driven Design

Table 4.
Updated AI-based tools in the design process (adapted from Croce, 2024).

Data Research Analysis

1. Tableau AI
2. DataRobot
3. Determ
4. Brandwatch
5. Chattermill
6. ATLAS.ti
7. Birdeye
8. Brand24

9. Replika
10. Chat GPT
11. Synthetic Users
12. QoQo

13. Crayon
14. YouScan
15. Piktochart
16. Kroma

17. Miro Assist

Creative AI

18. Collaborative Ideation Partner (CIP)
19. Stable Diffusion
20. Midjourney
21. DALL-E
22. Microsoft Bing image creator (Designer)
23. Jasper.ai
24. Leonardo.Ai
25. BlueWillow
26. Let's Enhance
27. Artiphoria.ai
28. AutoDraw
29. Vizcom
30. Prome AI

31. Magic studio
32. Flair
33. Towards a Co-creative System for Creating, Suggesting, and Assessing Material Textures for 3D Renderings During Design Reviews in Industrial Design

Graphic Design Tools

34. Adobe Firefly
35. Adobe Sensei
36. Remove.bg
37. Movavi
38. Fronty
39. Walling
40. Canva
41. Designs.ai
42. Adobe Express
43. Visme
44. Sketch2Code
45. Deep art Effetcs
46. Uizard
47. Fontjoy
48. Looka
49. Decktopus
50. Figma

51. A Predictive and Generative Design Approach for Three-Dimensional Mesh Shapes Using Target-Embedding Variational Autoencoder
52. Co-Design with Myself: A Brain-Computer Interface Design Tool that Predicts Live Emotion to Enhance Metacognitive Monitoring of Designers
53. OwnDiffusion: A Design Pipeline Using Design Generative AI to preserve Sense Of Ownership

3D Generative Design

54. Fusion 360
55. Creo generative design
56. nTop Platform
57. Siemens NX Shape Optimization
58. MSC Apex Generative Design
59. Rhino + Grasshopper
60. CATIA Generative Design Engineering
61. Solidworks Simulation
62. NETVIBES One Part
63. NVIDIA OptiX™ AI-Accelerated Denoiser
64. Design Target Achievement Index: a differentiable metric to enhance deep generative models in multi-objective inverse design
65. A Novel Self-Updating Design Method for Complex 3D Structures Using Combined Convolutional Neuron and Deep Convolutional Generative Adversarial Networks

66. An artificial neural network tool to support the decision making of designers for environmentally conscious product development

Table 5.
List of tools in the design process (adapted from Croce, 2024).

design processes take a more systematic approach in addressing complex problems. However, they still tend to frame problems within relatively narrow spatio-temporal contexts and do not offer a comprehensive approach for identifying all stakeholders and addressing their conflicts. A more holistic approach is needed to address problems that will take dozens of years or even decades to resolve (Irwin, 2018, p. 969).

To conclude, while new areas of design were developed to address problems with a more systemic approach, product design was developed by adding features to typical design process structures. These phenomena will likely continue, while only new comprehensive approaches could eventually let us tackle today's complex problems. So, the contemporary challenges will impact how design transitions into new domains or develops new processes, approaches, methods, and tools. In contrast, design will take part in the change, sharing its way of tackling problems.

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